Volume 15 MAY 1931 Number 5

BULLETIN
of the
American Association *of* Petroleum Geologists

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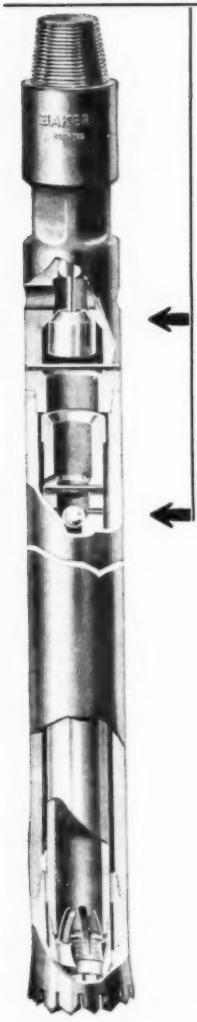

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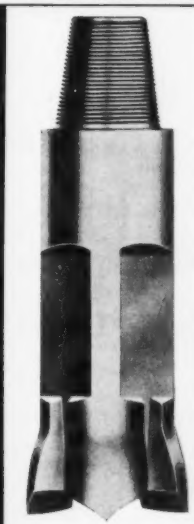

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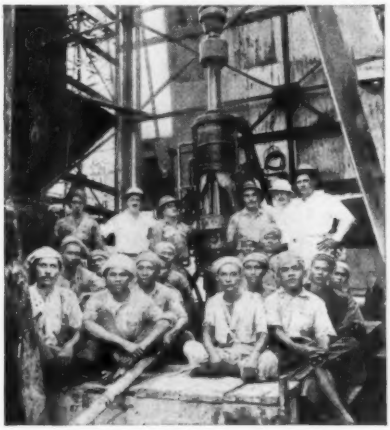

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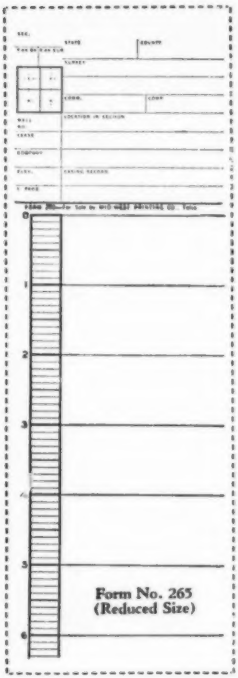

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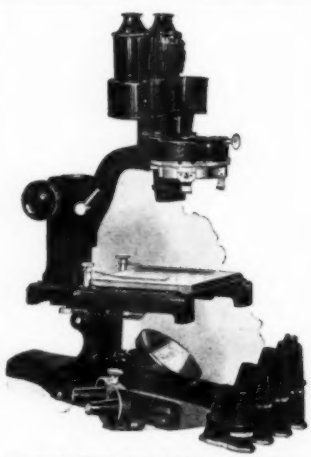

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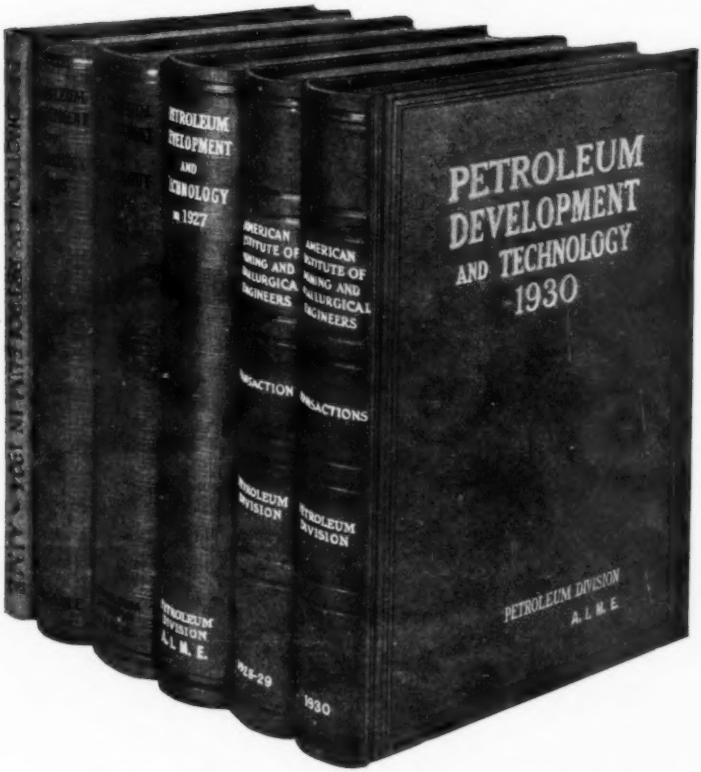

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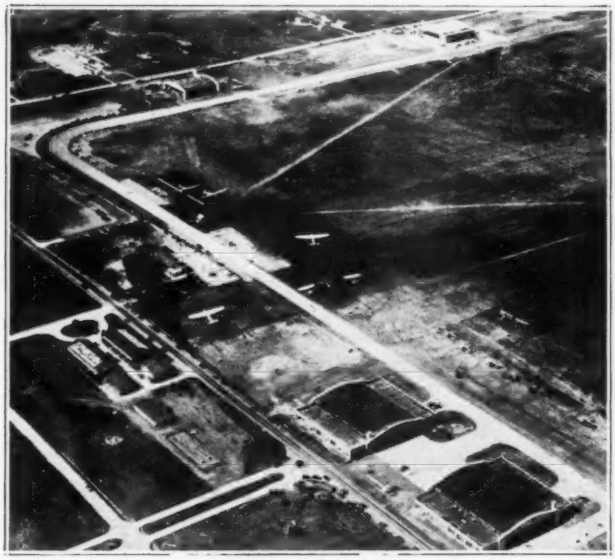

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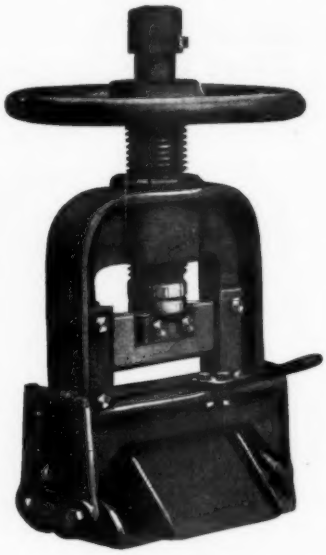

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Volume 15 Number 5

BULLETIN

of the

AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS

MAY 1931

ALBERTA SYNCLINE, CANADA[1]

THEODORE A. LINK[2]
Calgary, Alberta

ABSTRACT

Results of recent drilling operations, as well as a general consideration of surface evidence, seem to indicate that the great Alberta (Edmonton) syncline is extremely asymmetrical and that its deepest part lies directly beneath, or very close to, the eastern edge of the Foothills Belt rather than a distance of 12-15 miles eastward. This is an inheritance from the larger and older Cordilleran geosyncline. The significance of such a possibility with respect to the possible accumulation of oil or gas and drilling depths is briefly discussed.

INTRODUCTION

Publications on western Canadian geology are not very numerous in the pages of this *Bulletin*. As no areal geological map of the Province of Alberta has ever been submitted with the few papers pertaining to the geology of this province, the writer believes that such a map might be useful in this contribution on the Alberta or Edmonton syncline. With the permission of John Allan, of the University of Alberta, at Edmonton, the generalized areal map (Plate 1) is submitted. A comparative table of formations and nomenclature giving the equivalent Canadian and American names is also submitted as Table I. As the Alberta Society of Petroleum Geologists is sponsoring a symposium on the detailed stratigraphy of south and central Alberta, no attempt is made in this paper to assign exact thicknesses to the different formations. The Alberta Society

[1]Presented before the Association at the New Orleans meeting, March 21, 1930. Manuscript received, January 7, 1931. Published by permission of O. B. Hopkins, chief geologist, Imperial Oil, Ltd., Toronto, Ontario.

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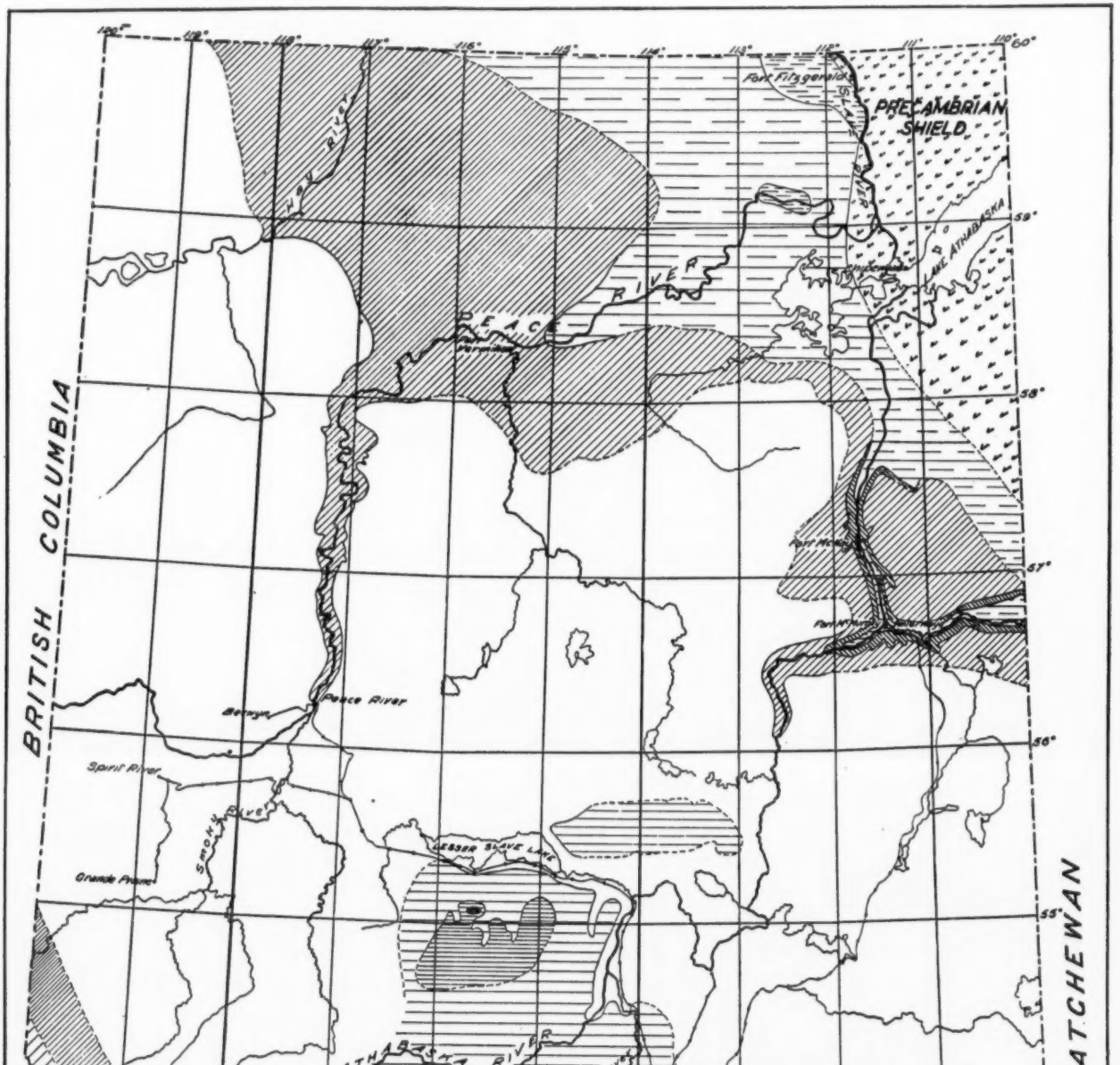
		FOXHILLS S.S.		HORSETHIEF S.S.	
		BEARPAW SHALES		BEARPAW SHALES	
	BELLY RIVER SERIES	PALE BEDS S.S. & SH.		JUDITH RIVER BEDS	TWO MEDICINE
		FOREMOST BEDS S.S. & SH.			
		PAKOWKI SHALES		CLAGGETT SHALES	
		UPPER MILK RIVER S.S.		UPPER EAGLE	EAGLE S.S.
		LOWER MILK RIVER S.S.		VIRGELLE S.S.	
		BENTON SHALES		COLORADO SHALES	
		CROWSNEST VOLCANICS			
		BLAIRMORE BEDS		DAKOTA ?	
		KOOTENAY		KOOTENAI	
JURASSIC		FERNIE SHALES		ELLIS SHALES	
PALEOZOIC		MADISON L.S.		MADISON L.S.	

hopes to assemble these papers and to submit them for publication in this *Bulletin* in the near future.

Like all undrilled major structural features, the great Alberta syncline is a subject of considerable speculation. The maximum depth of this syncline, the approximate position of its axis, the presence or absence of oil, gas, connate or fresh waters, et cetera, are a few of the unknown features which operators and geologists in Alberta would like to know more about. During the last decade several well intrenched ideas regarding the supposedly tremendous depths of sedimentary basins and thicknesses of individual formations have been radically revised by results obtained from deep drilling by venturesome operators. The gen-


PRECAMBRIAN SHIELD
BRITISH COLUMBIA
SASKATCHEWAN
Fort Fitzgerald
Fort McMurray
Fort Vermilion
Peace River
Grande Prairie
Smoky River
Spirit River
GREAT SLAVE LAKE
LAKE ATHABASKA
ATHABASKA RIVER
PEACE RIVER
HAY RIVER
60°
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114°
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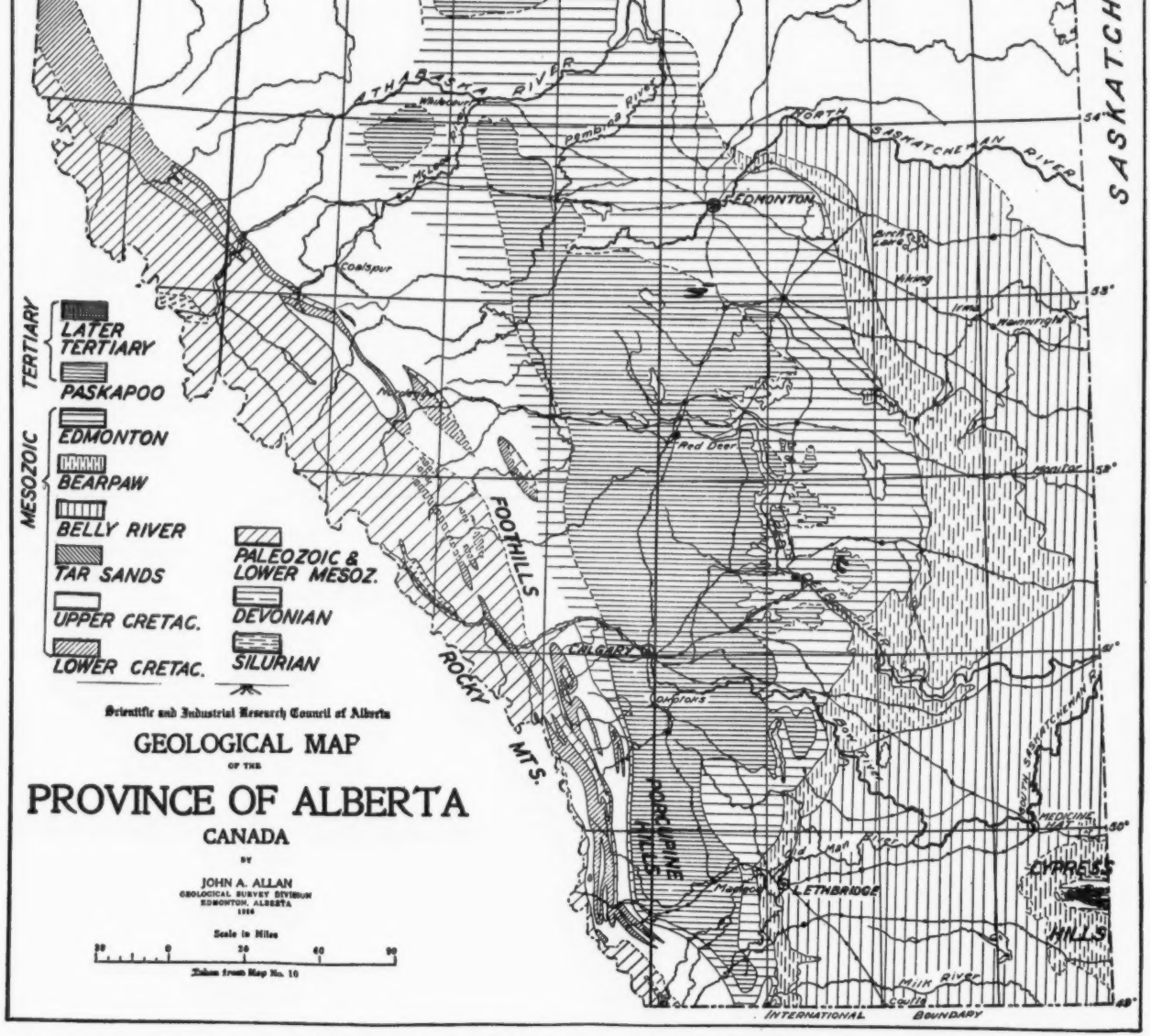

PLATE I.—Generalized areal geological map of Alberta. (Published by permission of Professor John A. Allan, University of Alberta, Edmonton, with minor alterations.

erally accepted idea regarding the position of the Alberta syncline is best expressed by this quotation from Hume.[1] "Eastward from the foothills the rocks dip eastward into what is generally known in southern central Alberta as the Alberta Syncline." The cross section in Figure 1 illustrates a generally accepted idea regarding the Alberta syncline, and the map in this same figure is taken from one by D. B. Dowling[2] illustrating his interpretation of this major structure. From exposures alone, Hume's statement and Dowling's map seem to be correct. However, deep drilling data now available suggest that the syncline in the underlying limestone and possibly in the Mesozoic does not coincide with that in the Tertiary.

CORDILLERAN SYNCLINE

The Alberta syncline is a direct descendant of the much greater Cordilleran geosyncline from which the Rocky Mountains and the Foothills arose. The Alberta syncline has inherited many characteristics from its ancestor. All students of North American geology know the general outline of events which culminated in the building of the Rocky Mountains.[3] The following summary is presented merely to refresh the memory and for use as a basis in the discussions to follow.

BRIEF HISTORY OF EVENTS RESULTING IN ALBERTA SYNCLINE

1. Deposition of the pre-Cambrian sediments in a relatively narrow, deep asymmetrical geosyncline connected with the Pacific Ocean. The deeper part of this basin lay west of the present Rocky Mountains.

2. The deposition of Paleozoic sediments on top of the pre-Cambrian strata without interruption by diastrophic movements of the first order. The deeper part of this broader geosyncline lay somewhat east of the pre-Cambrian site of greatest deposition as indicated by an unconformable contact of Devonian on pre-Cambrian in the Purcell Range. This Paleozoic geosyncline was much wider and extended considerably

[1]F. H. McLearn and G. S. Hume, "The Stratigraphy and Oil Prospects of Alberta, Canada," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 11, No. 3 (March, 1927), p. 255.

[2]D. B. Dowling, S. E. Slipper, and F. H. McLearn, "Investigations in the Gas and Oil Fields of Alberta, Saskatchewan and Manitoba," *Canadian Geol. Survey Mem. 116, Geol. Series 98, Pub. 1780* (1919).

[3]For an excellent and detailed account of the geological history of the Rocky Mountains the reader is referred to R. A. Daly's classic, "The Geology of the North American Cordillera at the 49th Parallel," *Canadian Geol. Survey Mem. 38*, Part 2 (1912), pp. 567-72.

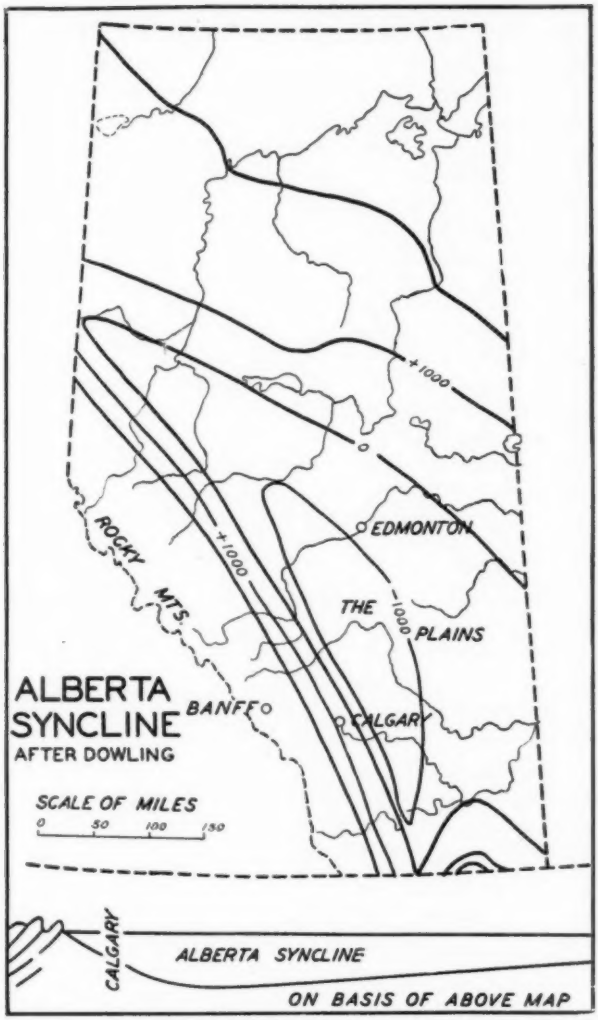

FIG. 1.—Generalized map of Alberta taken from *Canadian Geol. Survey Mem. 116, Pub. 1780*, showing Dowling's interpretation of Alberta syncline. Diagram is a generalized cross section taken from map.

farther eastward than the previous one. A study of Schuchert's well known paleogeographic maps[1] will emphasize this point.

3. Broad, differential upwarp at the close of Paleozoic time. Possibly only a slight interruption of deposition in the deepest part of the geosyncline, as evidenced by the absence of an angular unconformity between the Triassic and the Paleozoics in the Banff area. The eastern or shallower part of the Paleozoic geosyncline suffered greater erosion (without intense folding or faulting), as indicated by the truncation of older beds eastward from the mountains toward the pre-Cambrian Shield.

4. Encroachment of the Triassic and Jurassic seas from the Pacific Southwest, with sites of greatest accumulation at, or only slightly eastward from, the previous greatest depth of Paleozoic deposition. Vulcanism and slight diastrophic movements during this period.

5. Deposition of Lower and Upper Cretaceous sediments in a broad, widespread geosyncline whose deepest part lay close to the site of the present Rocky Mountains. This encroachment of the sea came from the Gulf of Mexico and the Arctic. Volcanic extrusion of local significance as evidenced by the Crowsnest volcanics above the Blairmore beds.

6. Diastrophic movements of the first order involving sediments of pre-Cambrian, Paleozoic, and Mesozoic strata, resulting in the building of the Rocky Mountains and Foothills. Erosion contemporaneous with, and subsequent to, Tertiary continental sedimentation in the shallow Alberta syncline lying east of the Foothills Belt. Local freshwater and inland-lake deposits within the mountains.

7. General uplift of land, additional folding and faulting, raising practically all of the Tertiary beds above present sea-level.

Canadian geological literature is replete with accounts and records showing that the greatest accumulation of sediments during pre-Cambrian, Paleozoic, and Mesozoic times was in that part of the Cordilleran geosyncline now occupied by the Selkirks, the Rockies, and the Foothills. The gradual thinning of these beds eastward toward the Canadian Shield is a well known and established fact. However, the greatest observed thickness of Tertiary sediments is immediately east of the Foothills Belt in what is to-day called the Alberta syncline. The Tertiary beds are separated from the underlying Mesozoic (Cretaceous) rocks either by one major, or a series of smaller, unconformities. It seems impossible to assign the break between the Tertiary and Mesozoic sediments to one single widespread unconformable plane.

[1]Charles Schuchert, *A Text Book of Geology. Part II. Historical Geology.* Revised edition (John Wiley & Sons, Inc., New York, 1924).

A few examples illustrating conclusively the thickening of sediments westward are offered. The Blairmore (Dakota) and Kootenay section along Crowsnest River[1] is at least three times greater in the Rocky Mountains than in Turner Valley, which lies at the eastern border of the Foothills Belt. In the Blairmore region the total thickness of Fernie, Kootenay, and Blairmore is 3,735 feet, though in Turner Valley the thickness of the same section is only 1,300 feet.[2] The Paleozoic section in the Rockies is also tremendously greater than it is at the east. There is no evidence whatever of Permian or Triassic beds in Turner Valley and the Fernie (Jurassic) is only 200 feet thick. The presence of Pennsylvanian beds is also questionable. Thus, of that part of the section representing the time equivalent of Permian, Triassic, and Jurassic, only 200 feet of beds are present in Turner Valley, and all of these are Jurassic, though near Banff, Alberta,[3] this same time interval is represented by at least 4,100 feet, comprising 700 feet of the Rocky Mountain quartzite (Pennsylvanian), and 3,400 feet of the Spray River (Triassic). No doubt considerable more could be added by means of a measurement of the Fernie (Jurassic) which is probably buried or cut off by faulting in the Banff area. In this same area Warren measured the Kootenay as 2,800 feet, more than twice as thick as the Blairmore-Kootenay section in Turner Valley (1,300 feet). It is true that an unconformity of considerable magnitude exists between the Paleozoic and the overlying Mesozoic rocks. This unconformity appears more like a disconformity where observed at the outcrops, or where considered in a limited area. However, if treated as a province-wide problem, it reveals the following interesting features. As one travels from west to east, or from southwest to northeast,[4] one finds progressively older Paleozoic rocks overlain by the Mesozoic. To be specific, near Great Falls, Montana,[5] the Jurassic (Ellis) beds rest unconformably upon the Quadrant (Pennsylvanian); in the Kevin-Sunburst[6] field, as well as in the Skiff area of southern Alberta,

[1]F. H. McLearn, "Mesozoic Paleontology of Blairmore Region, Alberta," *Nat. Mus. Canada Bull. 58, Geol. Series 50* (1929), pp. 82-96.

[2]Information from P. D. Moore, geologist, Royalite Oil Company, Turner Valley, Alberta.

[3]P. S. Warren, "Banff Area, Alberta," *Canadian Geol. Survey Mem. 153, Geol. Series 134* (1927), pp. 11 and 12.

[4]F. H. McLearn and G. S. Hume, *op. cit.*, p. 255.

[5]C. A. Fisher, "Geology of the Great Falls Coal Field, Montana," *U. S. Geol. Survey Bull. 356* (1909).

[6]Thos. B. Romine, "Oil Fields and Structure of Sweet Grass Arch, Montana," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 13 (1929), p. 789.

Jurassic beds rest unconformably on Mississippian strata; at Fort McMurray, Alberta, Cretaceous rocks (the Tar sands) rest unconformably upon Devonian limestones; and farther north in the Great Bear Lake region, Cretaceous rocks overlap the pre-Cambrian basement complex.

As already pointed out, in the Banff area Jurassic or Cretaceous rocks rest on Triassic, beneath which there is measured a great thickness of Pennsylvanian or Permian,[1] but at Turner Valley the Jurassic beds lie unconformably on the rocks of Mississippian or Pennsylvanian age. Thus, this regional unconformity merely accentuates the excessive thickening of beds from east to west and places the original basement complex surface at greater depths westward.[2]

The Benton (Colorado) shales, which overlie the Blairmore (Dakota?) and locally the Crowsnest volcanics, also show a thickening from east to west. If the behavior of the Cardium sandstone, which lies at the top of the lower third of the Benton, can be used as an index, a thickening of the Benton shales within the Foothills Belt must also be assumed. In Turner Valley the Cardium[3] sandstone is not more than 70 feet in thickness and this corresponds closely with the writer's measurements on the Jumping Pound structure. Westward toward the mountains the Cardium sandstone becomes much thicker and at Kananaskis Falls Rutherford[4] found it to be 220 feet thick. The writer has found this westward thickening to extend throughout the Foothills area. In the Jumping Pound structure the Benton shales were found to be almost 2,700 feet thick, which corresponds closely with the Turner Valley measurements. There are no reliable figures available for the total thickness of the Benton westward toward the mountains except those given by Rutherford,[5] who estimated 3,450 feet, based on disconnected measurements along Bow River. If it is assumed that these are approximately correct, and if the thickening of the Cardium sandstone is considered, it is safe to state that the Benton (Colorado) as a unit also thickens considerably westward within the Foothills Belt, and that it becomes more sandy.

[1]P. S. Warren, *op. cit.*, pp. 11 and 12.

[2]One of the first geologists to point out to the writer the real significance and the effects of this regional unconformity in the northern Montana and southern Alberta area was Roy Lebkicher, of The California Company, Great Falls, Montana.

[3]P. D. Moore, personal communication.

[4]R. L. Rutherford, "Geology along the Bow River between Cochrane and Kananaskis," *Sci. and Indus. Res. Council, Prov. of Alberta, Rept. 17* (1927), p. 27.

[5]*Op. cit.*, p. 30.

In the Plains area numerous reliable Benton shale measurements give this formation a thickness slightly less than 1,800 feet, so that a gradual westward thickening of about 1,000 feet, as far as the outer Foothills, is a definite fact. The same can be stated definitely regarding the Belly River (Allison) series, comprising the Milk River, Pakowki, Foremost, and Pale beds of the Plains (Eagle, Claggett, and Judith River on the American side).

RECENT DEEP DRILLING DATA IN PLAINS

The greatest uncertainty in the geology of the Alberta syncline lies in the detailed correlation of members within those formations younger than the Foxhills sandstone (basal Edmonton or St. Mary's). Most drill-holes which commence above this formation do not definitely show the ultimate depth to the Paleozoic limestone until the drill encounters clearly recognizable beds in the Bearpaw or underlying formations. Exact correlations within the Bearpaw are now possible, but within the Belly River beds, especially toward the Foothills, where the Claggett (Pakowki) shales lose their identity, correlations are still uncertain. In the Turner Valley district and the surrounding Foothills, great strides have recently been made in the exact measurement of thicknesses and the subdivision of the Benton shales, the Blairmore (Dakota?), the Kootenay, and the Fernie. In consequence, the average total thickness from the base of the Belly River to the Paleozoic limestone in the Plains area and the outer Foothills Belt is well known. The gradual thickening of the sediments westward within the Plains is again emphasized from the most recent deep drilling results.

As an interesting illustration of this gradual increase in thickness, the Alberta Pacific Consolidated's Spring Coulee Well No. 1 (Sec. 15, T. 4, R. 23 West of 4th), furnishes pertinent data.[1] When this well was spudded in somewhere in the basal St. Mary formation, the expectation was that the Paleozoic limestone would be encountered at a depth of about 5,200 feet. Thicknesses approximating those measured in the Red Coulee field at the east were assumed. The hole is now down to a depth of about 4,800 feet in the Benton shales. An increase in thickness of the Belly River series amounting to about 600 feet has already made it necessary to change the expected depth of the Mesozoic-Paleozoic contact to about 5,800 feet. An increase of thickness in the Benton, the Blairmore-Kootenay, and possibly the Fernie (Ellis) shales would

[1]W. S. Yarwood, geologist, Alberta Pacific Consolidated Oils, Ltd., Calgary, Alberta, personal communication.

extend the ultimate depth to the limestone to a larger figure.[1] To be brief, if no tangible results are forthcoming in regard to more exact correlations of the highest Cretaceous and the Tertiary beds of the Alberta syncline, the exact depth to the Paleozoic will always be an uncertain matter for wildcat tests drilled at a considerable distance from previously completed bore-holes.

INFORMATION FROM DEEP TESTS IN TURNER VALLEY AND VICINITY

In the opinion of the writer many wells have already been sunk very close to what may technically be termed the deepest part of the Alberta syncline, namely, those in Turner Valley. The few wells in Turner Valley which have passed through the major overthrust fault underlying this structure furnish pertinent data on this subject. One of these wells, British Dominion No. 1, was spudded in with the best of intentions to test the east flank of the Turner Valley structure. Drilling commenced in the Benton shales and the drill remained in these shales for 5,480 feet. A thrust fault of considerable magnitude was then encountered and the drill finished in what seem to be Belly River (or possibly younger) beds at a depth of 6,525 feet. The actual thickness of beds in Turner Valley from the base of the Belly River sandstone to the top of the Paleozoic limestone is about 3,900 feet.[2] Under the assumption that the beds below the 6,525-foot mark are lying horizontally, and under the added assumption that drilling ceased in the lowest Belly River beds, it would be impossible to reach the Paleozoic limestone at a depth less than 10,425 feet in British Dominion No. 1. The two assumptions are undoubtedly not correct,[3] and it seems perfectly safe to state that the limestone lies at a depth of more than 12,000 feet along the eastern border of the Turner Valley structure. This is the outer fold of the Foothills Belt which exposes a Benton shale core at the surface.

In the Sterling Pacific well, which is near the southern end of Turner Valley, the drill passed from Paleozoic limestone through an overthrust fault at a depth of 6,436 feet. A core taken below the fault shows a dip of more than 60°, and the formation looks very much like Upper Belly River or the equivalent of sandy Bearpaw shales. On the assumption that there is no dip of the beds below the fault plane, and with the addition of the necessary amount of stratigraphic column to the present depth,

[1]The top of the Paleozoic limestone was encountered at a depth of 5,965 feet at Spring Coulee No. 1 (March 30, 1931).

[2]P. D. Moore, Royalite Oil Company, Turner Valley.

[3]If the beds dip at an angle of 45° one must add 1,950 feet and if the drill is higher in the Belly River series, still more must be added.

the top of the Paleozoic limestone would be found at a depth of 12,136 feet (allowing 1,800 feet as the thickness of the Belly River series). If an average dip of 45° were assumed below the fault to the top of the limestone, the depth would be 14,986 feet. If it is assumed that the Blairmore, rather than the Belly River, was encountered beneath the fault, the limestone should lie at a depth of 8,386 feet. This assumption is probably not correct.

According to the most reliable data available, the Sentinel well, located on a sharp, faulted fold, ½ mile east of Turner Valley, ceased drilling in the Lower Belly River at a depth of 5,840 feet. This is the outer fold of the Foothills Belt (Fig. 2). If the Sentinel well is drilling in flat beds of the lowest Belly River series (probably an incorrect assumption), and if the lower column as measured in Turner Valley prevails, this well should strike the top of the limestone at approximately 9,740 feet. If an average dip of 45° is assumed, the depth would be 11,590 feet. If there is a gradual eastward dip for 10-12 miles from this well, as indicated on the older maps, the top of the Paleozoic rocks would be at a depth of about 15,000 feet in a line connecting Calgary and Okotoks.

Fortunately, another test, close to this line of strike 12 miles east of Turner Valley, yields data on this subject. The Anglesey-Lakeview well (L. S. 1, Sec. 22, T. 21, R. 1 West of 5th) was drilled to a depth of 4,500 feet. Excellent cores from the last 2,000 feet, revealing no perceptible dip, were available from this drill hole. All information indicates that drilling ceased in the Lower Belly River series. Using the average thickness as measured in the outer Foothills Belt and the nearest well drilled in the Plains area for the remaining section above the Paleozoic limestone, and assuming that the well ceased drilling near the base of the Belly River, one would expect to encounter the top of the Paleozoic at a depth of less than 8,000 feet in the Anglesey-Lakeview well (Fig. 2). The average thickness of Benton, Blairmore, Kootenay, and Fernie in Turner Valley is about 3,900 feet, though in the Plains section its average thickness is only 2,500 feet. With the necessary correction for difference in elevation calculated, which is only 300 feet, it becomes evident that the top of the Paleozoic rocks should lie structurally higher in the Anglesey well than on the downthrown block beneath Turner Valley or at the Sentinel well. If it is assumed that the deepest part of the Alberta syncline lies east of the Anglesey well, as indicated on Dowling's map (Fig. 1), it is necessary to postulate a structure of considerable size at this well or between it and Turner Valley. As there is no surface evidence to

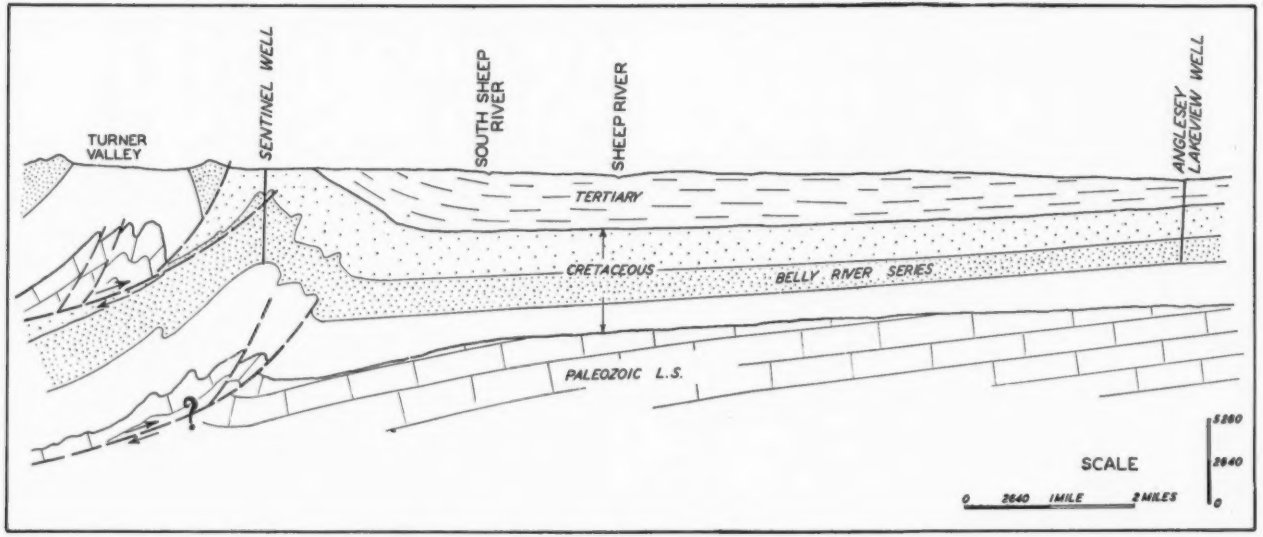

FIG. 2.—Cross section from Foothills Belt eastward for 12 miles. Constructed on b of information presented in this paper. Vertical and horizontal scale the same. Notice regional unconformity between Paleozoic and overlying Me ic beds, as well as thickening of beds westward. Turner Valley structure is generalized and part beneath main overthrust fault is hypothetical. Vertical scale in feet.

support this view, it seems necessary to conclude that an angular unconformity, or a series of unconformities, exists between the Upper Cretaceous and the overlying Tertiary beds, and that the deepest part of the Alberta syncline (with respect to Mesozoic and Paleozoic rocks) lies close to, or beneath, the outer or easterly border of the Foothills Belt, that is, the downthrown side of the Turner Valley structure, as indicated in Figure 2.

PORCUPINE HILLS AREA

In the Porcupine Hills area, an outlier of Tertiary beds lying directly east of the Foothills Belt, evidence can be found supporting a gentle westward dip to within a mile or two of the outer sharp Foothills fold. Extremely high cross bedding and erratic dips on true bedding planes are common throughout the Porcupine Hills, but a view of the rocks in these hills from points south of Oldman River discloses the gentle westward slope reversed rather sharply toward the east very close to the outer faulted fold of the Foothills. Likewise, on St. Mary River, south of Cardston, Alberta, detailed work by Sanderson[1] shows that the surface trace of the deepest part of the Alberta syncline lies less than 2½ miles east of the outer overturned Foothills fold.

SHIFTING OF SITE OF DEPOSITION

A little more space will be given to further data relating to the localities where the greatest column of sedimentary rocks was deposited from pre-Cambrian to the present time. The publications of the Canadian Geological Survey pertaining to Alberta and British Columbia show conclusively that the sedimentary beds in the Plains area represent a mere sheet resting on the pre-Cambrian complex, though in the Rocky Mountain area and westward miles of sediments were piled up. According to Warren,[2] the following composite section is present in the Rocky Mountains near the 51st parallel of latitude.

	Feet
Upper Cretaceous	3,000
Lower Cretaceous	4,000
Jurassic	1,600
Triassic	3,500
Carboniferous	4,500
Devonian	3,200
Silurian	1,200

[1] J. O. G. Sanderson, geologist, Imperial Oil, Ltd., Calgary, Canada.

[2] P. S. Warren, "Sedimentary Record in the Rocky Mountains at about the 51st Parallel," *Canadian Field-Naturalist*, Vol. 43 (1929), pp. 23-27.

(*Continued*)	*Feet*
Ordovician	2,800
Cambrian	23,200
Pre-Cambrian	5,910
Total	52,910
	(or approximately 10 miles)

Reference to the individual publications from which these figures were obtained are given in Warren's paper. It is of interest to note that Daly[1] reports a total thickness of 61,150 feet of pre-Cambrian rocks alone in the Selkirks which lie west of the Rocky Mountains. The first reaction to the figures in the preceding column is to doubt that such a tremendous series of sediments was ever deposited. The writer has taken the time to review the numerous publications of the Canadian Geological Survey pertaining to the Rocky Mountains and has found that, although the field investigators do not agree on the exact total thicknesses of the pre-Cambrian and Paleozoic sediments, the order of magnitude of the sediments is essentially as given.[2]

In the northeastern corner of Alberta, Devonian and Silurian rocks overlap the western edge of the Canadian Shield, which comprises the true pre-Cambrian basement complex (Plate 1). If Daly's figures are correct, the pre-Cambrian sedimentary sheet must have had the shape of an asymmetrical lens 12 miles deep in eastern British Columbia and thinning out to almost nothing eastward. This is, of course, under the assumption that the beds measured in the Selkirks lay one on top of another without omissions and that no pre-Cambrian sediments were deposited on the shield. Likewise the Paleozoic sedimentary sheet, which to-day amounts to only a few hundred feet near the edge of the shield, increases to 47,000 feet (approximately 9 miles) in the center of the Rocky Mountains. The Mesozoic sediments, represented by a few hundred feet along the Athabaska and McMurray rivers in northeastern Alberta, increase to 12,100 feet in the Banff area. Finally, the Tertiary beds, as exposed in the southeastern part of Alberta and Saskatchewan, show an increase in thickness westward toward the Porcupine Hills, which lie immediately east of the Foothills Belt.

These data point strongly toward Grabau's[3] idea of a *progressive eastward shifting of the geosynclinal trough of deposition from pre-Cam-*

[1] R. A. Daly, *Canadian Geol. Survey Mem. 68* (1915).

[2] John A. Allan, *Canadian Geol. Survey Mem. 55* (1914); R. A. Daly, *Mem. 38* (1912) and *Mem. 68* (1915); S. J. Schofield, *Mem. 76* (1915); J. D. MacKenzie, *Mem. 87* (1916); and P. S. Warren, *Mem. 153* (1927).

[3] A. W. Grabau, "Migration of Geosynclines," *Bull. Geol. Soc. Amer.*, Vol. 30 (1919), p. 87.

brian to the present. The relatively thin sheet of sediments deposited during Tertiary time is, therefore, what is to-day called the Alberta or Edmonton syncline. Before the final disturbance or uplift affected these Tertiary deposits they represented the last vestige of the true Cordilleran geosyncline of deposition which had been shifted slowly toward the east because of the several disturbances which have taken place since pre-Cambrian time. Each shift found the deepest part farther east but shallower, as indicated in Figure 3.

The Alberta syncline, like its predecessors, is decidedly asymmetrical, with the axial plane dipping gently westward. In considering this entire group of Cordilleran geosynclines, the asymmetry is even greater. When dealing with the mechanics of the structure in the Rocky Mountains, the Foothills Belt, and the Plains area, cognizance of this inheritance must be taken. Although the undisturbed planes of deposition would have a tendency to slope eastward away from the land mass which supplied the bulk of the sediments, the floor of each sedimentary basin would sink deepest directly beneath the locus of greatest accumulation. This sinking or down-warping of the floor would also cause the planes of deposition to be bent correspondingly. The sediments lying directly above the floor of the basin would suffer the greatest downward bending and the overlying strata would show progressively less downward bending. This would result in a narrow belt of relatively steeply inclined beds sloping toward the east away from the land mass to a zone directly above the deepest part of the geosyncline. This would be the steeper and narrower flank of the asymmetrical geosyncline of deposition. The wider, gentler, and westward-dipping flank would extend from the locus of deepest downwarp eastward to the opposite relatively lower land mass—the pre-Cambrian Shield.

ACCUMULATION OF OIL, GAS, AND WATER

The effects which the shape of the Alberta syncline may have upon the accumulation of oil or gas are of interest, but give rise to considerable speculation. Up to the present, the following broad generalities can be stated regarding the occurrence of hydrocarbons. Dry gas has been encountered in sands of the Benton shales, the Virgelle sandstone (lowest Belly River), in the so-called Kootenay of the Plains area, and also the Ellis (Fernie). All of these occurrences of dry gas are confined to the upper part of the east flank of the Alberta syncline, and their geographic distribution is of considerable extent. Extremely heavy oils have been encountered in small quantities in Lower Cretaceous and Jurassic beds

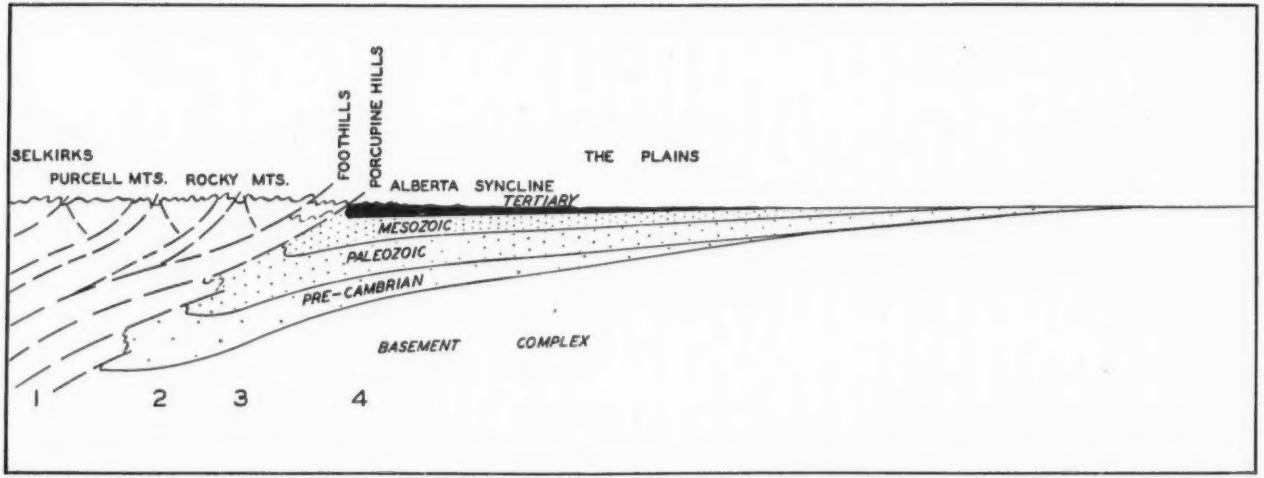

FIG. 3.—Ideal or generalized cross section through Rocky Mountains, Foothills, and Plains, illustrating asymmetry of Cordilleran geosynclines and their successor, the Alberta syncline. Progressive eastward shifting of sites of greatest deposition from pre-Cambrian to Tertiary time is indicated by numbers 1-4. Diagram is not drawn to scale and thicknesses and distances are merely relative. Interpretation of Rocky Mountain structure is purely hypothetical.

of the Plains area, and in the small Red Coulee field at the International Boundary a medium-grade crude is produced from beds within the Ellis or Kootenay formations, just above the Paleozoic limestone. The production of wet gas, from which naphtha is recovered, is confined to the Paleozoic limestone of Turner Valley. In addition, a relatively small amount of extremely high-grade crude is encountered in the Blairmore and Kootenay in Turner Valley. The wet gas in Turner Valley is under an extremely high pressure.

There is a possibility that some member or members of the Upper Cretaceous beds on the gentle east flank of the Alberta syncline may contain water under considerable head. This head would be derived primarily from the Sweet Grass Hills area and along the pre-Cambrian Shield. The east flank of the Alberta syncline is, as shown in Figure 2, the downthrown side of the Turner Valley overthrust fault.

This source of pressure from the south and east might, in part, account for the high pressure in the Paleozoic limestone in the upthrown part of the Turner Valley fault block. It seems doubtful that a hydrostatic head within the Paleozoic limestone of Turner Valley could arise from the west because of the presence of the almost countless thrust faults west of the valley. O. B. Hopkins[1] has pointed out that this hydrostatic pressure would probably not be sufficient, even if effective. He believes that the Turner Valley pressure might be caused by reduction of size of reservoir through faulting and folding or by generation of gas in the rocks themselves. This seems to the writer very probable.

An alternative for the foregoing is the possibility that the water within the Paleozoic limestone, which lies at depths of 10,000-15,000 feet on the downthrown side of the Turner Valley thrust fault, may have a head derived from the plains at the south and east, and that still farther west, at depth, the limestone on the downthrown side may be in contact with that on the upthrown side of the Turner Valley overthrust fault; thus, a hydrostatic head from the east may find its way back up the west flank of the limestone on the upthrown side. If the south end of Turner Valley is not cut off by the low-angle overthrust fault, water from the Alberta syncline within the Paleozoic limestone could find its way directly into the structure, thus causing some of the pressure. These suggestions are mere speculations and should not be taken too seriously.

The scattered occurrences of dry gas and heavy oils in the Plains area might be caused by an original migration up the east, gentler flank of the Alberta syncline into local structures or suitable sand conditions,

[1]Personal communication.

such as lenses. If this is true, a search should be made for pronounced folds farther down the slope (westward) of the gentler flank of the Alberta syncline. At present, such an undertaking might be regarded as somewhat premature because of the great depths at which the possible producing zones lie.

The possibility of a flushing of the east flank of the Alberta syncline is also worthy of consideration. If the main thesis of this paper is correct, flushing from the west seems improbable. Therefore, the flushing of structures in the Plains area must be considered as caused by waters entering the sands either along the outcrops which circle the igneous uplifts of the Sweet Grass Hills or those paralleling the pre-Cambrian Shield. If this is true, accumulation of oil or gas would be expected on the northwest or west part of structures found in the westward-dipping flank of the Alberta syncline. If future drilling reveals the presence of a considerable amount of stagnant water in the deepest part of the Alberta syncline, it is obvious that as soon as this eastern level is established, further drilling will be guided by such determinations.

Finally, failure to encounter productive horizons in the Paleozoic limestones of the Plains may be caused by the progressively lower beveling of these older rocks at the east before the deposition of the Jurassic beds, as indicated in Figure 2. The Turner Valley productive horizon had evidently been eroded away in the Plains area prior to the deposition of the Mesozoic beds.

CAP-ROCK PETROGRAPHY[1]

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ABSTRACT

With a profusion of well cores available, the Freeport Sulphur Company undertook their utilization for further petrographic study during the summer of 1930. The following paper is a part of a report on that work, and records the minerals and rock structures observed in approximately one hundred and fifty thin sections. Conclusions seemingly substantiated by the study are (1) the sedimentary nature of the anhydrite, (2) its probable Glen Rose age, (3) alteration of the anhydrite to form the calcite and gypsum caps, (4) further evidence of intrusive nature of salt stock and cap rock, and (5) primary origin of sulphur, in part.

INTRODUCTION

Existing knowledge of salt-dome structures is largely summarized in three volumes, published by The American Association of Petroleum Geologists. The earliest of these is *Geology of Salt Dome Oil Fields*, published in 1926, and the other two constitute the two-volume symposium, *Structure of Typical American Oil Fields*, published in 1929.

In brief review, a salt dome consists essentially of a stock-like mass of nearly pure rock salt, extending from unknown depths into overlying sediments. The top of the salt mass in many of the American domes is remarkably flat, and is succeeded above by a characteristic series of rock materials known collectively as the "cap." The cap and salt stock present a roughly circular horizontal outline, ranging in diameter from a few hundred feet as at Sulphur, Louisiana, to 4 or 5 miles as at Hockley, Texas. The salt stock is believed to have intruded the surrounding and abutting sediments in response to enormous stresses, the extent of penetration ranging from that at Goose Creek, where the deepest drilling has yet failed to encounter the cap rock, to that at one or two of the Five Islands, where the salt mass has nearly reached the surface.

The cap series at the base is uniformly massive anhydrite. Upward this passes in many domes somewhat abruptly into a fine-grained calcite. These two parts are known, therefore, as the "anhydrite cap" and "cal-

[1]Published through the courtesy of the Freeport Sulphur Company, Freeport, Texas. Read before the Association at the San Antonio meeting, March 19, 1931. Manuscript received January 29, 1931.

[2]Department of geology, University of Texas.

cite cap," respectively. In other domes the anhydrite passes upward into massive gypsum, called the "gypsum cap," which may or may not be succeeded by the calcite cap. These cap materials are typically non-fossiliferous and non-abrasive. They are referred to as "true cap," to distinguish them from a hard calcareous sandstone, commonly fossiliferous, that in places overlies the whole, known as "false cap."

In a few domes a concentration of sulphur is found in the calcite or gypsum cap, ordinarily most plentiful just above the anhydrite. There may be several enrichments, but toward the top of the cap the sulphur becomes greatly dispersed or is absent, and the cap is referred to as barren.

The principal paper on the petrography of cap rock is that of M. I. Goldman, in the first volume previously mentioned. In that paper the secondary nature of the calcite, gypsum, and sulphur is demonstrated, and the sedimentary origin of the anhydrite stated as probable. The gypsum is shown to originate by hydration of the anhydrite, and inferences are drawn that the calcite and sulphur occur through reduction of anhydrite by penetrating hydrocarbons.

The present investigation was undertaken by the Freeport Sulphur Company, during the summer of 1930. The company had a profusion of well cores from properties at the Hoskins Mound and Bryan Heights salt domes, with many more available from prospects elsewhere and as a result of the interest and coöperation of other organizations. The work consisted almost entirely of the preparation and microscopic examination of thin sections at a well-appointed laboratory at Bryan Heights.

During this time about one hundred and fifty thin sections were prepared. Ten of these were of irrelevant materials and eight were duplicates. Each section, together with the hand specimen it represented, was separately described. The routine detailed descriptions are given in the original report, but their bulk forbids their inclusion in this article. Generalizations and conclusions were drawn from the study of these separate descriptions. The numerical and geographical distribution of these is as follows.

*Locality**	*Number of Sections*
Hoskins Mound	49
Bryan Heights	12
Black Bayou, Louisiana	8
Boling dome	7
Gulf Hill, Matagorda County	18
Long Pointe	15
Hockley dome	3
La Fourche Parish, Louisiana	1
Sulphur, Louisiana	1

Locality (Continued)	*Number of Sections*
Liberty dome	1
Humble dome	13
Clemens dome	1
Miscellaneous	3
Unknown location	1
Total different cap-rock sections	133
Duplicates	8
Irrelevant	10
Total	151

*Texas, unless otherwise indicated.

CONCLUSIONS

The major conclusions that seem to be supported by this study follow.

1. The salt structure is caused by a vertical intrusion of the salt stock and true cap, under enormous pressures, to a variable extent, and from unknown depths.

2. The anhydrite is of normal primary marine crystallization.

3. The anhydrite caps of the Gulf Coastal salt domes represent parts of the same sedimentary formation; that is, may be correlated as of the same age.

4. There is some evidence that this age is the Glen Rose equivalent of the Comanche.

5. The calcite of the calcite cap is secondary through direct alteration of the underlying anhydrite by carbonate waters of meteoric origin.

6. Gypsum of the gypsum cap is also secondary through direct alteration of the anhydrite by circulating meteoric waters low in carbonates.

7. An important part of the sulphur is syngenetic with the anhydrite.

8. Commercial sulphur deposits of salt domes are at least partly secondary accumulations of primary sulphur.

9. Evidence of reduction of anhydrite by contiguous or penetrating hydrocarbons is obscure or lacking.

DISSERTATION

Movement.—In the cap-rock series, there is plentiful evidence of movement. Brecciation is so common as hardly to deserve mention. Faulting and slickensides are in evidence throughout. Brecciation is especially pronounced in the upper zones of the cap, where it is accom-

panied by large amounts of wide-veined white calcite, ordinarily with some evidence of aragonite. With depth, however, this vein width decreases; the irregular brecciation becomes less intricate, less evident, and early passes into a regular parallel banding of light and dark materials, in many places with bands of sulphur. The banding is uniformly at a marked angle to the core, ranging from 45° to 60°. It becomes progressively more perfect, may be traced through the transitional series, and into the massive anhydrite. Progressive steps in this change are illustrated by Figures 1-5. These are fragments of 6-inch cores, from different wells, selected because of size or clarity of illustration. All are from Hoskins Mound, but, as they do not constitute a continuous core, depths would be meaningless and are not given.

In the anhydrite, the banding changes from an alternation of different minerals to a series of fine white striations, which are illustrated ideally in Figure 5. This is a 5-foot section of a 6-inch core, taken from approximately 24 feet below the anhydrite-calcite contact, and at a total depth of nearly 1,600 feet, Hoskins Mound. Sections made across the white striations show no different materials, but exhibit a marked gneissic parallelism, illustrated in Figure 8. The white streaks of the hand specimen are evidently caused by the mashing of the anhydrite along parallel shear planes, just as mashing dark colored anhydrite with a hammer produces a white mass.

Of the one hundred and thirty-three different cap-rock sections, fifty-three are of more or less unaltered anhydrite, and, of these fifty-three, fifty, representing every dome mentioned in the Introduction, were found to exhibit a similar mashed and gneissic texture in greater or less degree. In addition to the gneissic texture of the thin section and corresponding macroscopic striation, other evidences of mashing are (1) strain shadows, (2) twisted and broken cleavages, (3) irregular, ragged outlines of constituent grains, (4) comminution of grains, (5) occurrence of small ragged flakes of one orientation within larger grains of another orientation, and (6) control of the shear planes over fracture (notice each end of core shown in Figure 5), and diffusional circulation, as is shown later. These features are partly illustrated in Figure 9.

The universal presence of these features is unquestionable evidence of profound movement. Moreover, the remarkable extent and parallelism of the high-angle banding indicates the direction of the forces producing the movement. This parallel shearing is evident, uniformly from top to bottom of the cap, from flank to flank, and from dome to dome. There is clear indication of an intrusion of overlying sediments by the

salt stock and cap in response to an enormous stress exerted vertically below, and, equally as important, indication of a movement continuing, if not originating, long after the cyrstallization and consolidation of the cap-rock minerals.

Anhydrite cap.—Mineral relations and the mineral assemblage observed in the fifty-three anhydrites are as follows: dolomite, calcite, celestite, quartz, sulphur, pyrite, hematite, magnetite, glauconite, tourmaline, gypsum, galena, sphalerite.

Dolomite was identified by (1) persistent occurrence in typical perfect rhombs, (2) negative uniaxial character, (3) resistance to hydrochloric acid solution, and (4) index of refraction above 1.68 observed.

Dolomite rhombs occur in all sizes, ranging from ultra-minute inclusions within the anhydrite grains, to interstitial individuals as large as the anhydrites. Their repeated occurrences as inclusions proves them syngenetic with the anhydrite. Also, the larger individuals are present in the most compact anhydrites. They occupy an individual place in the fabric, there is no trace of corrosion of the contiguous anhydrite grains, and no evidence of any channels through which they might have entered epigenetically.

Dolomite in primary relation was observed in forty-three of the fifty-three massive anhydrites. (See Figures 10, 11, 12, 13, and 14.)

Calcite, in cap rock, is so widespread in its secondary scalenohedral occurrence that it is difficult in many specimens to determine its syngenesis or epigenesis with anhydrite. That it does occur in part syngenetically is proved by its repeated occurrence as inclusions within anhydrite grains. In this occurrence it may show perfect hexagonal outlines, but ordinarily it appears as anhedral equidimensional flakes. Its occurrence in definite primary relation with the anhydrite was noticed in all dolomite-bearing sections.

In the fifty-three massive anhydrites, celestite was observed in primary relation in six sections. Its primary character is shown by small interstitial crystals in massive unaltered anhydrite. It is readily distinguished from anhydrite by (1) higher relief, (2) poorer cleavage, (3) low birefringence, and (4) negative biaxial character (Fig. 21).

Barite is not distinguished from celestite, and is inferred as possibly or probably present where celestite is mentioned. No spectroscopic tests showed strontium without barium, or vice versa. The strontium line without exception appeared more strongly, however, and for this reason celestite is mentioned rather than barite. Another factor supporting this choice is the index of refraction. In repeated Becke tests, the index was not above 1.63.

Quartz, in euhedral crystals, was noticed in thirty-nine of the fifty-three anhydrites. The crystals are short hexagonal prisms, doubly terminated, with the positive and negative rhombohedrons almost equally developed. A unique structure is the "rosette," in which perfect singly terminated crystals radiate in all directions from a center or nucleus of sulphur, here and there a pyrite grain, or in places a flake of carbonate. These unique crystal clusters in the massive anhydrites are not ordinary occurrences in thin sections. Only three or four perfect median sections were observed, though partial sections were considerably more numerous.

Euhedral quartzes occur as inclusions within anhydrite grains, and in all sizes, ranging from minute particles to crystals a little larger than the average anhydrite. Rosettes also have been noticed as inclusions, but these, with the larger crystals, ordinarily occupy interstitial positions. All are syngenetic with the anhydrite. None shows any interior detrital nucleus, with secondary enlargement, as in quartzites, but some contain as inclusions specks of sulphur, or pyrite (Figs. 15, 16, 17, and 18).

Both pyrite and sulphur occur epigenetically in profusion in the calcite cap. From these occurrences to the minute inclusions within anhydrite there is a transition so complete and gradual that it is impossible to set an exact boundary between that which is all primary, and that which is all secondary. Persistent inclusions, however, must be syngenetic, and forty-seven such occurrences of sulphur were noticed, and forty-six of pyrite, in the fifty-three anhydrites. As inclusions, sulphur particles are ordinarily plentiful in the dolomite rhombs, and pyrite is somewhat less common.

Hematite was noticed in seven of the anhydrite sections. The mineral appears as a matrix embedding unaltered anhydrite grains. It seems to be primary, but is not definitely determined.

Glauconite appears in five of the sections. In four of these it occurs as minute, drop-like inclusions within anhydrite and dolomite, and its identification was tentative, until in the fifth it appeared interstitially in its customary facies,—rounded, nearly cryptocrystalline aggregates. As inclusions, especially within dolomite rhombs, it must be syngenetic with the anhydrite.

Tourmaline has not been observed in any anhydrite thin sections, nor has any other mineral of necessarily detrital facies. However, in the solution of an anhydrite specimen from Bryan Heights, one minute acicular tourmaline was recovered in the residue,—a zoned specimen, one end being water-clear and the other deep blue with the characteristic strong dichroism.

Gypsum was noticed in seven of the massive anhydrites, but everywhere presented a secondary facies. Other miscellaneous minerals include the following: galena, identified unquestionably in two occurrences but inconclusive as to primary or secondary relations; sphalerite, noticed in three or four places, occurring only as minute inclusions, evidently primary. Its identification is not unquestionable, being based on poorly observable characters. It is deep brown, with high refractive index, and seems to be isotropic, though these characters are masked by the anhydrite. The presence of galena might be considered a confirmatory factor.

From the foregoing observations is derived the conclusion that the anhydrite is a normal primary deposit in an evaporating sea. In summary, the reasons for this conclusion are as follows: (1) the practical omnipresence of syngenetic dolomite, a mineral widely accepted as of marine origin; (2) the occasional presence of syngenetic glauconite, a mineral yet more definitely marine; (3) the existence of identical common and various unique characters in all of the anhydrites examined, though the several domes geographically are widely separated; (4) the existence of identical common and various unique characters in all of the anhydrites examined, though the several dome caps have penetrated the overlying formations to widely different geologic levels; and (5) the persistent occurrence of anhydrite in association with rock salt, syngenetic celestite, and barite, these being minerals of wide occurrence and common association in recognized marine facies.

It will be remembered that syngenetic celestite was observed in only six anhydrite sections, which might seem too few for dependable generalization. However, strontium and barium were detected spectroscopically in all anhydrites examined, irrespective of location, and this observation might reasonably imply the existence of the syngenetic sulphates. There are two reasons why they might be present and not detected in thin section: (1) the distribution is so sparse that the small area of a thin section could easily fail to include any, and (2) possible, though less probable, celestite and barite, present in small amounts, might crystallize isomorphously with the anhydrite, thus being masked from view.

A further observation indicative of primary marine origin of the anhydrite is shown in Figure 20, which illustrates the structure of the three anhydrites not showing mashed and gneissic texture. It may be called the "pile-of-brick" structure, from obvious similarity. It evidently represents a mass of rectangular euhedral grains, and probably indicates that to be the character of all sedimentary anhydrite textures prior to physical distortion.

These three anhydrites represent the Liberty and Humble domes. Each of the specimens was close to, or in contact with, the salt. It has also been common experience to obtain quantities of such euhedral anhydrite grains as residuals from solution of the salt. Precipitation of anhydrite due to saturation in a given sea basin would give rise to myriads of euhedral forms, which, settling and accumulating upon the sea floor, might easily produce structures similar to this. The absence of indications of mashing is probably due to the more facile flowage of the adjacent salt.

If the primary sedimentary origin of the anhydrite is accepted, it may be said further that the anhydrite caps of the several domes are all parts of the same sedimentary formation. This correlation is indicated in the identity of the structures, textures, and common minerals, and positively confirmed in the repeated occurrence of identical unique characters. Among these are euhedral quartzes, especially the "rosette" structure, and syngenetic celestite.

Celestite also gives a clue to the age of this common formation. Celestite is known to occur widely through the Glen Rose formation (Comanche) in central Texas. The writer has had occasion to study this occurrence, and has observed structures indicating its crystallization to be syngenetic with the limestone. These observations were recorded in a paper presented before the Mineralogical Society of America in December, 1929.[1] If the occurrence of the celestite is syngenetic in both the Glen Rose and the anhydrite caps, it is reasonable to conclude that the anhydrite formation is the southeastern equivalent of the Glen Rose; therefore, it is Comanche in age. This conclusion is further supported by the stratigraphic sections given in two papers on Caddo Parish, Louisiana. Crider[2] shows 450 feet of "anhydrite zone" between Upper and Lower Glen Rose limestones, and Fletcher[3] shows about the same thickness of Glen Rose anhydrite in his "west-east cross section through Caddo field."

Calcite and gypsum caps.—The upper parts of the calcite cap are extensively brecciated. The breccia fragments are ordinarily dark gray, in places almost black, and the cement a white calcite or aragonite. Boundaries between the two are not sharply defined under the micro-

[1]Abstract, "Types, Occurrence, and Probable Origin of Texas Celestite," *Amer. Mineralogist*, Vol. 15, No. 3 (March, 1930), pp. 121-22.

[2]A. F. Crider, "Pine Island Deep Sands, Louisiana," *Structure of Typical American Oil Fields*, Vol. II (Amer. Assoc. Petrol. Geol., 1929), pp. 170 and 172.

[3]Corbin D. Fletcher, "Caddo Field, Caddo Parish, Louisiana," *Structure of Typical American Oil Fields*, Vol. II (Amer. Assoc. Petrol. Geol., 1929), p. 191, diagram.

scope, indicating the source of the vein calcite to be at least partly through solution of the wall carbonate.

The breccia is ordinarily fine and even-grained, and the darker color is caused by finely disseminated pyrite in varying amounts. In the fine-grained carbonate secondary scalenohedra are persistently in evidence. There is also other evidence that the calcite cap is secondary, and originates from direct alteration of the underlying anhydrite by entering waters.

1. The alteration may be observed directly. The carbonate first appears interstitially in the massive anhydrite as myriads of minute particles, showing plainly the scalenohedron. Pyrite and sulphur particles may serve as nucleii. In the earlier stages, the interstitial crystallization produces a net-like appearance (Fig. 22). With further alteration, the number of calcites increases, and the anhydrite grains decrease in area. Eventually, the anhydrites disappear, and a medium- to fine-grained groundmass of the carbonate remains. Figures 23, 24, and 25 show this transition in a single core, well Gulf Hill No. 766. Figure 23 is of massive, dense anhydrite at 1,171-1,175 feet. Figure 24 is of more porous anhydrite, granular, at 1,158-1,167 feet. Figure 25 is a fine-grained carbonate at 1,153-1,158 feet. Ordinarily the transition is more abrupt than this. The disappearance of the anhydrite is attended with a development of carbonate in separate hexagonal crystallization. No pseudomorphs have been observed.

2. Sulphur is plentiful and widely dispersed through the carbonate in large patches, coarsely crystalline. Many, if not all, of these sulphur areas contain vestiges of anhydrite, ranging from ragged residual flakes and shreds to perfect pseudomorphs. The sulphur replaces the anhydrite, proceeding into the cleavages (Fig. 7). After complete replacement, the sulphur may show the outlines and cleavages of the original anhydrite grain.

Although sulphur replaces anhydrite, the replacement evidently is much less rapid than the replacement by carbonate. After embedding the anhydrite, the sulphur seems to isolate it from altering solutions. Rhombic dolomites and quartz crystals are seen in many of the sulphur patches, but secondary calcites are rare within. Such residual shreds, flakes, and pseudomorphs in massive calcite are not uncommonly the only evidence remaining of the former anhydrite.

3. The calcite cap contains unique characters recognized as of primary origin in the anhydrite. Most conspicuous of these are the euhedral quartzes, and especially diagnostic are the rosettes. Rhombs

of dolomite are also common, many having an irregular border of secondary growth.

4. Celestite is also an indicator of this alteration. It occurs widely and commonly in the calcite cap, everywhere in secondary facies. It is known to be primary in the anhydrite. The secondary occurrence reasonably indicates its release through destruction of the anhydrite.

The second most common epigenetic mineral is gypsum. This mineral may be observed directly forming from anyhydrite. It first appears in very narrow interstitial stringers, with large areas optically continuous. The anhydrite flakes become smaller and smaller within the mass of growing selenite, and eventually disappear.

In this transition, many of the anhydrite grains assume a peculiar shape. The three faces of anhydrite do not dissolve with the same ease. When treated artificially, the 001 and 010 faces are very resistant to solution, but the 100 faces are easily corroded. When viewed parallel to 100, the outlines are rectangular, but from 001 they appear much like the hull of a battleship. This shape is characteristic of anhydrite corrosion, and many of these peculiarly shaped grains have been observed within the large gypsum matrix (Fig. 19).

There is no evidence of waters of exceptional nature producing the alteration to carbonate or to gypsum. Circulation of waters containing carbonates could result in nothing more easily than direct replacement of anhydrite, a condition of differential solubility. It is a pleasure, also, to acknowledge W. Lindgren[1] as an original proponent of this view of the origin of the calcite cap. The secondary carbonate is perfectly clear, and gives no evidence of release of sulphur in the replacement process, as would probably be the fact if the carbonate resulted from reduction of the anhydrite by carbonaceous material. Moreover, if reduction had occurred, there should be some vestiges of the reducing material, and nothing of that nature has been recognized.

Carbonate waters are of common occurrence in the shallower part of the earth's crust. It would be difficult to imagine an intrusion from great depths reaching the surface without passing through a stratum of carbonate waters. There are several wells, whose average depth is 500 feet, on the coast, in the vicinity of Freeport, Texas, with copious artesian flows of carbonate waters.

Sulphate and chloride waters likewise are by no means exceptional. Circulation of waters of this type, if the chloride is not too concentrated,

[1]Personal communication. Dr. Lindgren visited the laboratory several times in the early part of the summer.

as in waters near saturation, would result in simple hydration of the anhydrite, a change that has been observed in many sections from Bryan Heights, Sulphur, Louisiana, and elsewhere, and is not entirely unknown from Hoskins Mound. No evidence of reduction or of reducing agents has been observed in connection with this process.

Entry of altering waters seems to follow the shearing planes previously described, which likewise seem to facilitate this diffusional movement. Here is to be found the origin of the high-angle banding of secondary minerals, so prominent in the lower parts of the calcite cap. Diffusion borders, sharply outlined on one side and gradually fading out on the side of water encroachment, are commonly observed. Figure 4 shows a series of narrow bands of pyrite. In Figure 6 the high-angle banding is less regular and perfect, but apparent. In the upper third of the figure is an area with profuse secondary celestite, which mineral is absent from the lower part. Dividing these two areas are the narrow diffusion borders marking the temporary limits of the diffusional solutions.

Lastly, the common association of calcite and sulphur on top of anhydrite is the chief reason for the reduction theory, widely accepted as the origin of both of these minerals. If this is true, the origin of the sulphur in the gypsum cap becomes a more serious question, as sulphur occurs plentifully in this facies, seemingly without corresponding destruction of the sulphate molecule and without the appearance of calcite from supposed oxidized organic matter.

Sulphur.—It is not proposed here to include a full statement of sulphur origins. The petrographic facies of this mineral are too numerous and too varied for brief description. Many of the structures are easy to see but difficult to decipher, and time has not been available to make their significance clear. It is also probable that petrography alone can not completely solve the problem, and the petrographic phase is all that has been contemplated in this paper.

However, the reduction theory has been kept in mind throughout, with the hope that some minerals or structures might be observed bearing directly on this problem. In several sections a black fine-grained material and what seemed to be a precipitate of sulphur were observed in the same slide. One of the plainest of these is illustrated in Figure 29. Here celestite, formerly a large single crystal, as shown by simultaneous extinction, is now separated by considerable carbonate including a flocculent material resembling cryptocrystalline sulphur. Below are some indefinable patches of brownish black material. Here it seems are ideal

conditions. Yet the black material, with repeated qualitative chemical tests, proved to be iron and silica, soluble only in hydrofluoric acid, and tests for carbonaceous material were uniformly negative. Also, the residual sulphate as well contains a profusion of sulphur particles; therefore, the nature of the flocculent material remains questionable, and the cause of its occurrence there is unknown.

Anhydrite, saturated with hydrocarbons, was found in small quantities in several cores. Many sections of these were prepared, but they showed a fabric no different from the other anhydrites, with no corrosion borders or other evidence of destruction. Also, many cores from areas of prolific sulphur production were examined. These were ordinarily close to massive anhydrite, but the sulphur and calcite gangue were pure and did not show unquestionable evidence of hydrocarbons.

Although these observations are uniformly negative, they do not seem sufficient basis for a general conclusion, in view of the present slight understanding of many of the varied occurrences of sulphur. Awaiting further study, it can be stated only that evidence thus far of reduction of the anhydrite by entering contiguous hydrocarbons is vague or wanting.

It may be said, however, that a part of the sulphur is primary, that is, existed as sulphur prior to the crystallization of the anhydrite. Evidence for this may be summarized as follows.

1. Sulphur has been observed within the massive unaltered anhydrite. In the hand specimen it appears in light yellow spots, ranging in size from that of a pin head to ½ inch in diameter. Spots of the larger diameter are scarce, being separated by many feet. There are few anhydrites in which such sulphur occurrences can not be detected with the unaided eye, and Donald C. Barton[1] relates his observation of a similar sulphur particle in a core of massive rock salt at a depth of approximately 500 feet below the salt contact.

Sections of these sulphur spots show the sulphur as a matrix embedding anhydrite grains (Fig. 26). There are several bits of evidence tending to show its syngenesis in this occurrence with the anhydrite. 1. Many of the anhydrite grains display sharp rectangular borders in contact with the sulphur, though aside from these a mashed and gneissic texture is evident. 2. With reference to the sulphur patches in the calcite cap, containing residual flakes and shreds of anhydrite, it is evident that the sulphur was present as a matrix for the anhydrite grains prior

[1]Personal communication.

to the entry of carbonate altering solutions (Fig. 7). 3. Sulphur spots have been observed in anhydrite altering to gypsum. In many places the sulphur mass and anhydrite grains have intricately parallel boundaries, separated by a thin stringer of invading gypsum (Fig. 27). From these relations, it is clear that the sulphur was present interstitially within the anhydrite prior to the entry of the hydration fluids. 4. In the massive anhydrites no channels are visible through which sulphur could gain access to this situation, and no reason is apparent, if it had entered in such manner, for its stopping where it has. 5. If the anhydrite is a normal sedimentary deposit, and a similar occurrence of sulphur has been observed considerably within the earlier salt, it is clear that sulphur must have existed as such prior to deposition of the anhydrite.

2. Grains and specks of sulphur have been frequently mentioned in the descriptions of sections. These are minute particles, but large enough under the microscope to present recognizable identifying characters. Ordinarily they are sub-rounded, many are irregular, and a few are present in perfect euhedra, pyramidal and tabular. As inclusions in anhydrite grains, they are plainly syngenetic. Ordinarily, in such facies, their orientation is controlled by the cleavage, and many minute tabular forms may be observed. The anhydrite from Sulphur, Louisiana, showed a greater profusion of these sulphur inclusions than any other examined.

Dolomite rhombs and other primary carbonate areas commonly show a profusion of sulphur particles. In this situation there can be no doubt of their primary origin.

Sulphur particles have been observed as minute inclusions within quartz euhedra, and are especially well seen as centers of rosette clusters (Figures 15, 16, and 18). As the quartz occurs as inclusions within anhydrite, it is clear that the sulphur is also older, or primary.

Sulphur deposits of commercial dimensions in salt domes seem largely to be secondary accumulations of this primary sulphur. Evidence supporting this conclusion is as follows. 1. Sulphur travels as small particles in the currents of the altering solutions. These are illustrated in Figure 28, which shows secondary celestite with considerable sulphur strung out in small particles. Temperature may be an important factor in this transportation, but no observations are available on this point. 2. There is considerable evidence of concentration through removal of the gangue,—anhydrite, gypsum, and especially calcite being more or less easily soluble in percolating waters. The calcite cap is in many places

porous, or cavernous, and large amounts of calcium carbonate occur secondarily as a cement in the false cap. More conclusive evidence is the concentration in the calcite cap of minerals recognized as primary in the anhydrite. Among these are quartz crystals and rosettes, dolomite rhombs, and celestite. All of these minerals become several times more plentiful in the calcite cap, and have already been shown to be syngenetic with the anhydrite.

DISCUSSION

E. DEGOLYER, New York, N. Y.: Goldman, speculating on the results of his studies of cap-rock petrography, suggests that the origin of the cap from a bed of sedimentary anhydrite is indicated. Brown puts forward, among the conclusions "seemingly substantiated" by his studies, "the sedimentary nature of the anhydrite"—that it "is of normal primary marine crystallization" —and that it is of "probable Glen Rose age."

I do not regard these suggestions as proved by the data presented; in fact, many of the data may be used in support of the theory of residual origin of the cap as favorably as it is used to support sedimentary origin. In any event, Glen Rose age is as yet only an interesting speculation.

According to the theory of residual origin, the original anhydrite grains would be "of primary marine crystallization," disseminated in the salt or interbedded with it and contemporaneous in age with the salt. Growth of the cap would be from below by accretion of anhydrite grains left as a residue from the solution of the salt. One would expect the uppermost part of the cap to be oldest and most altered, physically and chemically, and its base, nearest the salt, to be the youngest and least altered part.

This sequence is borne out, so far as we know cap rock. Brown finds pronounced brecciation in the upper zones of the cap and its least altered phase at the base; finds in the cap near the salt, anhydrite composed of rectangular euhedral grains which do not show mashed and gneissic texture; and it was his common experience to obtain quantities of such euhedral anhydrite grains as residuals from solution of the salt.

Whether the residual theory explains satisfactorily the occurrence of various minerals syngenetic with the anhydrite is not certain. It seems to me, however, that it is as satisfactory as, and even more flexible in this regard than, any other theory of primary origin, inasmuch as some of the materials appearing syngenetically may have been deposited from the solutions which removed the salt in which the primary anhydrite grains were encased, thus indicating that the minerals may be pseudo-syngenetic rather than syngenetic with the anhydrite.

Cap rock, generally anhydrite or anhydrite-gypsum, is of such common occurrence, not only in the United States but in Mexico, Germany, and other salt dome regions, that it must be regarded essentially as a salt-dome phenomenon. Such being the fact, the conception of the casual plucking—always of anhydrite or gypsum—of a cap from some formation encountered by the salt in its upward movement, is a demand upon coincidence exceeding the limits of credulity.

I do not believe, either, that the origin of cap rock, so common and intimate a part of the whole salt-dome problem, can be definitely settled on the basis of petrographic evidence alone. Salt-dome students must give full consideration to the indicated, as well as the definite, conclusions of the petrographers, but the petrographers in turn must consider salt domes broadly, and give consideration to variations and similarities, to physical and chemical relationships, and to the geological and mechanical requirements of the broader problem of salt-dome origins, if they are to attempt its solution.

We are still lacking in petrographic studies—even in chemical studies—of the salt itself over a wide range of occurrence. Such studies would undoubtedly supplement the studies of the cap rock and might do much to clarify the matter of origin. It is to be hoped also that Professor Brown will be able to extend his petrographic studies of the cap rock, and to include cores of salt and of the known Glen Rose anhydrite.

MARCUS I. GOLDMAN,[1] Washington, D. C.: I have appreciated the opportunity of reading Professor Brown's paper and am pleased to find that with most of his observations I am in agreement. We are, moreover, in agreement in believing that the anhydrite of the cap rock is of sedimentary origin. We differ, however, in that Professor Brown believes, as I believed at the time of writing the earlier paper to which he refers, that the cap is a sedimentary bed of anhydrite brought up by the salt. I am now convinced that it is a recemented mass of anhydrite residual from the solution of the top of the salt stock of the salt dome. Moreover, there is this further difference between Professor Brown's views and mine which I think accounts for many of the divergences of our interpretations of phenomena other than the origin of the cap rock. Professor Brown seems to regard the theory of the origin of the anhydrite cap as a single bed of sedimentary anhydrite, as opposed to some theory of its entirely secondary origin by precipitation from solution in place. I have never held a theory which would not regard the original source of the anhydrite as sedimentary.

At the time of writing my earlier paper I had not familiarized myself with the German literature on salt domes. What I knew of the theory of the residual origin of cap rock by solution of the salt stock suggested to me its construction by the accumulation solely of the isolated anhydrite crystals which form the so-called "annual" layers. As I found large breccia fragments (shown in some of my illustrations) of what was apparently stratified anhydrite rock, I rejected this "residual" interpretation.

Through reading the German literature and seeing how the flat solution surface, the salt table of Barton, cuts off all the beds in the salt stock, I soon became aware of a very obvious factor that I had neglected, namely, that solid beds of sedimentary anhydrite in the salt are also freed by solution of the salt and form part of the residue which enters into the formation of the cap rock. The matrix of the fragments of these beds of anhydrite is composed in part, presumably, of the isolated crystals of the annual layers, and in part of débris

[1]Published with the permission of the acting director of the U. S. Geological Survey.

of the beds of anhydrite, all more or less recrystallized and cemented into a solid mass. This origin is the one I advocated in a paper presented before the Geological Society of America in December, 1928.[1]

In a paper now in preparation I am presenting this interpretation more fully on the basis mainly of evidence derived from a group of specimens, from the contact of salt and anhydrite, received through the courtesy of various Gulf Coast geologists. One of these specimens, received from R. C. Stewart of The Texas Company, from their State Bay St. Elaine No. 3, Terrebonne Parish, Louisiana, shows a breccia fragment of which the stratification lamination is so perfect as to leave no doubt of its sedimentary origin. But particularly significant is material from the contact of salt and anhydrite in the shaft at Hockley. This specimen shows good, roughly horizontal and parallel banding, the lower band being an intimate intergrowth of salt and anhydrite crystals. This relationship conforms well with the assumption of the residual origin of the anhydrite cap rock, the lowest layer being one in which the removal of salt and the cementation of the anhydrite is not yet complete. It also explains the one feature of the cap rock that most puzzled me at the time of writing my 1925 paper, namely, the low angle to horizontal, roughly parallel banding of the anhydrite cap rock, illustrated, for example, in my Figure 13, and less perfectly in my Figure 11. The coincidence of the banding in the specimen from Hockley with the boundary between a layer containing intergrown salt and a solid layer free from salt, seems to me to show clearly that there is a periodic process in the formation of the cap rock which accounts for these bands. Their slope in the higher parts of the cap is probably due to the bending of the cap as a whole by upward thrust of the salt. This interpretation of the bands is different from the one offered in the paper before the Geological Society of America.

The structure of the anhydrite in its intergrowth with salt in the bottom layer is very similar to the "pile-of-brick" structure described by Professor Brown. As he mentions finding it at or near the contact of the anhydrite with the salt, it probably has the same origin.

It must be realized, however, that this explanation of the origin, though it emphasizes two constituents in the cap, the fragments of beds of anhydrite and the matrix of cemented and partly recrystallized fine anhydrite, does not account for all the differences to be seen in the character of the anhydrite of the anhydrite cap, which has undergone much recrystallization, some of it attacking the fragments of anhydrite beds.

If, however, we accept this distinction between the recrystallized matrix of the cap rock and the fragments of original sedimentary anhydrite beds inclosed in it, this at once changes the interpretation of many facts observed in the cap rock and reduces the probability of the primary origin of many of its constituents, that is to say, their origin within the sedimentary salt series (from which the salt stock is presumably extruded), before the removal of the salt by solution at the top of the stock. It follows, for instance, that the characters and contents of the anhydrite matrix are not necessarily

[1] An abstract of this paper appeared in *Bull. Geol. Soc. Amer.*, Vol. 40 (1929), pp. 99 and 100.

all derived from the salt, but that some may have been added during its removal from the salt and its subsequent cementation.

But there is, in addition, ample justification for assuming that even after its consolidation solutions penetrated especially the more porous matrix, rearranged its constituents and introduced new constituents, and it is not clear why Professor Brown is ready to accept the intimate penetration by calcifying and sulphurizing waters of which he sees evidence in the zone of transition from anhydrite cap to calcite cap, and yet is not willing to accept similar penetration as an explanation of many features, such as the occurrence of sulphur, in the lower part of the anhydrite cap.

My observations agree with Professor Brown's as to the occurrence of sulphur throughout the anhydrite cap rock, but to me penetration and molding of the anhydrite by the sulphur in the midst of a body of anhydrite rock have always seemed to be evidence in favor of the secondary origin of the sulphur. The fact that it is almost everywhere, if not everywhere, associated with a profusion of fine-grained carbonates, of the type that compose the calcite cap rock and that are irregularly distributed in the anhydrite, evidently in relation to seams of greater permeability, is very strongly in favor of its epigenetic introduction by the same processes as those which formed the calcite cap.

The great scarcity or the absence of sulphur and calcite in the denser, more impermeable fragments of sedimentary anhydrite beds in the cap rock also points to its secondary origin in those parts of the anhydrite cap rock in which it is found.

Professor Brown recognizes the absence of a definite distinction between the sulphur of the calcite cap rock, which he regards as epigenetic, and the sulphur of the anhydrite cap rock, which he regards as essentially syngenetic, in saying that there is a complete transition from one to the other. But even if we were to admit that much of the sulphur in the anhydrite cap rock is syngenetic, the quantitative aspects of the problem of deriving the sulphur of the calcite cap from it seem difficult. In actual amount it is probably a fraction of 1 per cent of the anhydrite cap rock and great quantities of the cap rock would have to be dissolved to yield the vast amounts of sulphur found on some salt domes. Sulphur, however, is 23.5 per cent of anhydrite. It would, therefore, take very much less anhydrite to yield the sulphur of the cap rock by reduction of anhydrite than by its solution.

That anhydrite and gypsum can be reduced by petroleum hydrocarbons has been demonstrated by Cadman's experiments.[1] I am not assuming, however, as Professor Brown seems to, that such a reduction has occurred at the point at which the sulphur and calcite are found. I have taken for granted that it occurs at the edge of the cap rock adjacent to its contact with the surrounding sedimentary beds, where it would encounter hydrocarbons derived from these beds or moving up along the contact of the salt core from deeper beds. From here, I assume, the calcium carbonate and sulphide or sulphur are carried in solution into the cap rock,—in much greater quantities into its upper part. That no reduction of anhydrite was noticed in an oil-soaked core is inconclusive,

[1]Reported in a paper published in *Jour. Inst. Petrol. Technologists* (London), Vol. 11 (1925), pp. 487-89.

as conditions of temperature, pressure, and solution would probably be important factors in the process.

To prove that such reduction occurs at the edges of salt-dome caps would probably require carefully planned observations of processes now going on there. But certain lines of evidence seem to me to favor the assumption of the origin of the sulphur by reduction of calcium sulphate. Professor Brown believes that the calcite of the calcite cap is derived from ordinary ground waters, seemingly assuming that the greater solubility of gypsum as compared with other rocks is responsible for its precipitation. Leaving out of the discussion the difficult question of the origin and circulation of waters around the tops of salt domes, there remains the consideration that this assumption ignores the fact, pointed out in my 1925 paper, that calcification affects all sorts of sedimentary rocks around the top of the salt dome, as in the "false" cap referred to Professor Brown. Evidently, therefore, the calcification is something connected with the salt dome. The sulphur is intimately connected with the calcification. Hence, we have a mass of calcite and sulphur intimately associated with a mass of calcium sulphate. The implication is strong. Certainly one would at least be inclined to believe that the two came from the same direction, though Professor Brown, as I understand him, holds the opinion that the sulphur comes from below, the calcite from above.

There are several points made by Professor Brown which it will not be necessary to consider in this general discussion. As Professor Brown and I do not differ about the ultimate sedimentary origin of the anhydrite of the cap rock, the association with strontium and barium does not enter into the discussion.

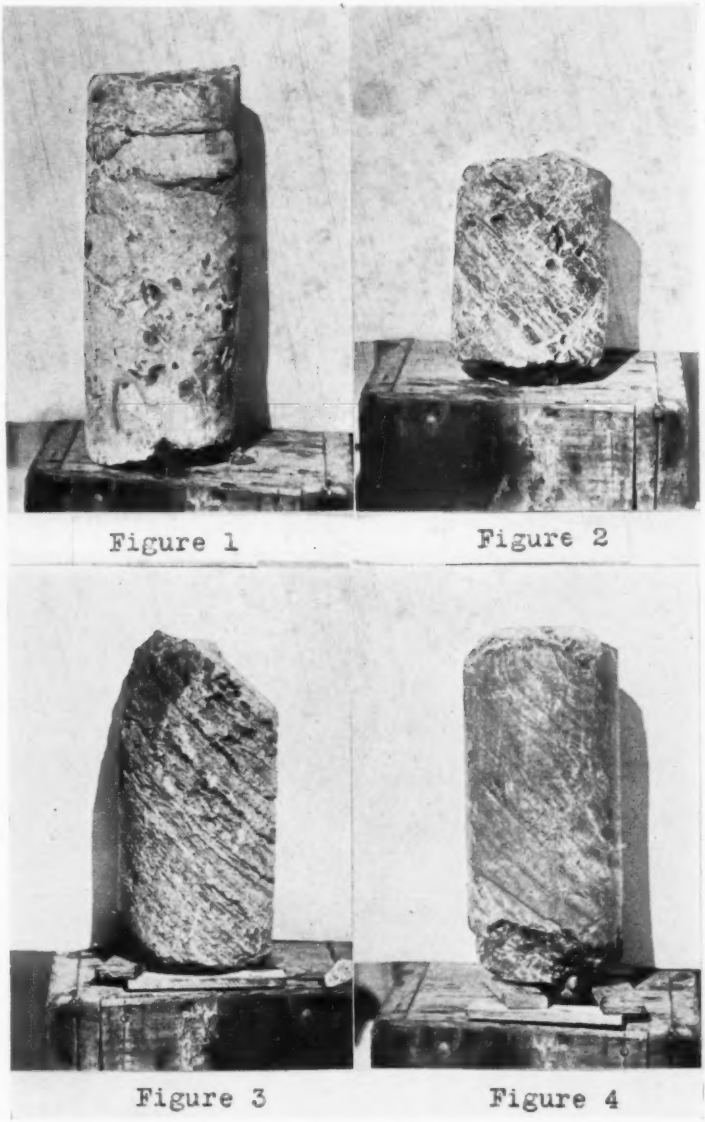
All known evidence would be opposed to the formation of glauconite in the concentrated waters in which calcium sulphate precipitates. But there is much evidence to support the belief that the calcium sulphate, as well as the calcium carbonate, of salt dome caps is carried into adjacent sedimentary beds and forms secondary masses by crystallization from solution. It seems to me probable that the glauconite described by Professor Brown got into the anhydrite by crystallization of the anhydrite from solution in the neighborhood of a sedimentary bed containing it, or else that it was a stray detrital fragment carried from some older sedimentary bed into the body of water in which the calcium sulphate was precipitating.

From my interpretation of the origin of the anhydrite cap rock it follows that I do not regard the cap rocks of different Gulf Coast domes as parts of the same bed, though I think they may all be derived from the same salt sequence. The resemblances Professor Brown notes are such as are common to anhydrite and such as would result from a common mode of origin and general history.

My remarks may be summarized thus.

1. Professor Brown and I differ in that he seems to regard the cap rock as an original sedimentary bed and I regard it as secondarily formed by cementation of sedimentary anhydrite freed from the salt stock by solution at its top surface.

2. As a corollary it follows that (a) I do not regard the anhydrite caps of the Gulf Coastal salt domes as representing parts of the same sedimentary



FIGURES 1 to 5 show progressive changes with depth in cap rock.

FIG. 1.—Much brecciated and recemented carbonate, toward top of cap.

FIG. 2.—Brecciated carbonate, with semblance of banding beginning to appear.

FIG. 3.—Banding becomes more regular, and consists principally of alternate sulphur and porous calcite bands.

FIG. 4.—Shows banding more sharply outlined in massive calcite core. Also shows narrow diffusion bands of fine-grained pyrite. Notice that bands are sharply outlined below and gradually fade out above.

Figure 5

Figure 6

Figure 7

FIG. 5.—Massive anhydrite, with profusion of parallel white striations resulting from shear in response to compressive stress.

FIG. 6.—Lower half of core is principally sulphur, appearing as darker gray. Above this are several narrow diffusion bands, below an area of much secondary celestite.

FIG. 7.—Ground mass of sulphur, with a few flakes and shreds of surviving anhydrite enclosed. Notice that sulphur is creeping into cleavages and replacing anhydrite. Plane polarized light; magnification, 26 diameters.

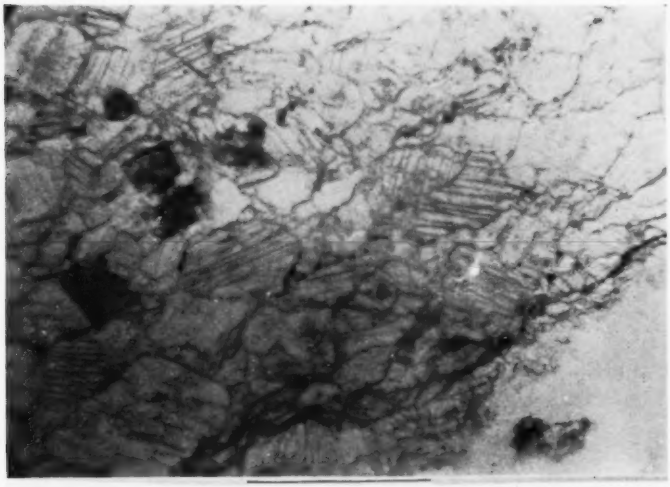


Figure 8

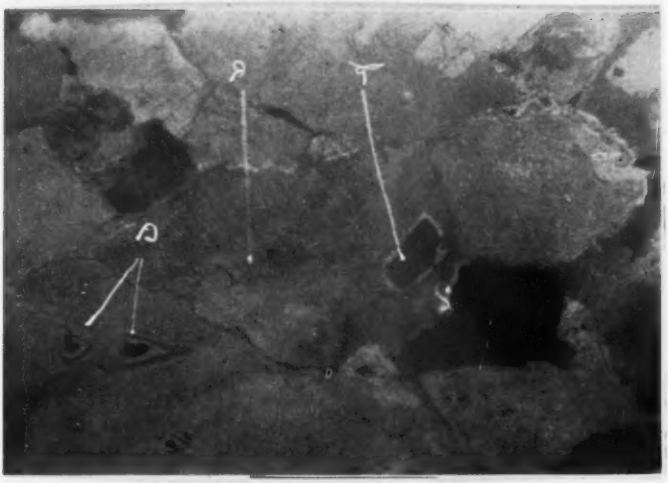


Figure 9

FIG. 8.—Massive anhydrite, showing gneissic texture. Plane polarized light; magnification, 26 diameters.

FIG. 9.—Massive anhydrite. (a) Large grain showing strain shadows and twisted cleavage. (b) Contained fragment of anhydrite in another orientation. (c) Cleavage particles removed in grinding. Crossed nicols; magnification, 80 diameters.

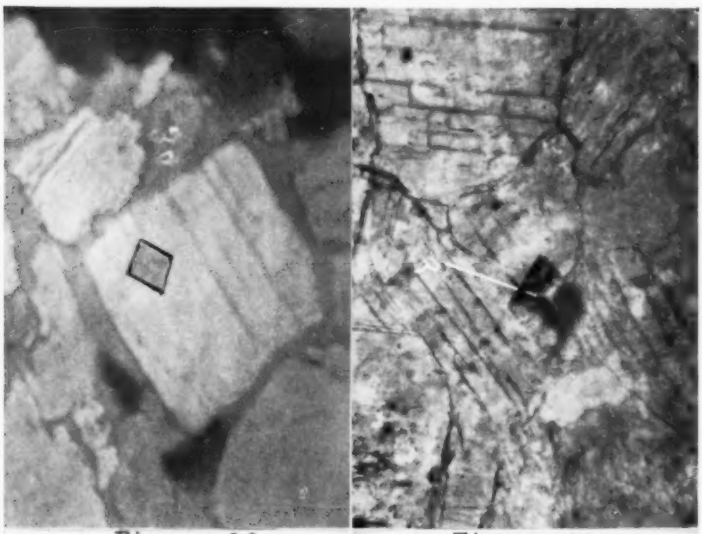


Figure 10 Figure 11

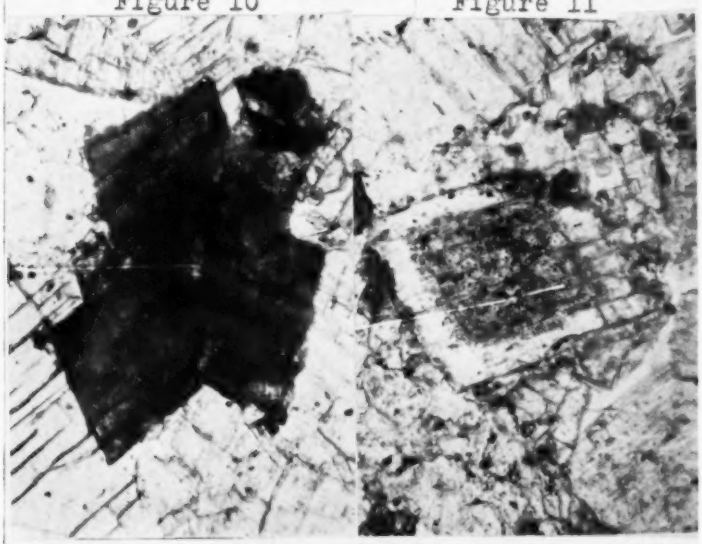


Figure 12 Figure 13

FIG. 10.—Grain of anhydrite, showing minute rhombic dolomite inclusion. Crossed nicols; magnification, 80 diameters.

FIG. 11.—Massive anhydrite, showing dolomite rhomb. Plane polarized light; magnification, 80 diameters.

FIG. 12.—Massive anhydrite, showing brecciated dolomite. Plane polarized light; magnification, 80 diameters.

FIG. 13.—Zoned dolomite. These occur throughout cap-rock series; this specimen is from calcite cap. Plane polarized light; magnification, 80 diameters.

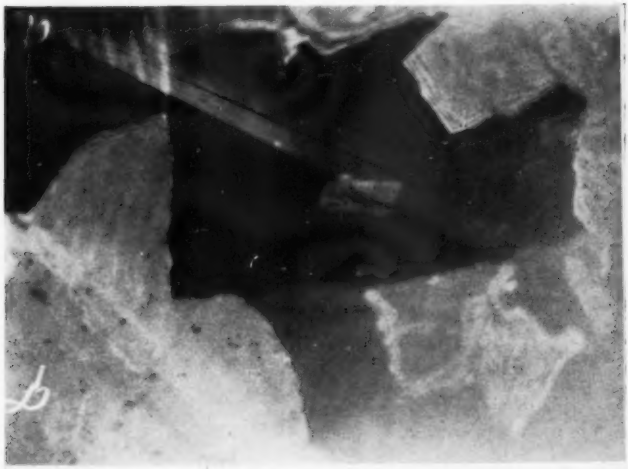


Figure 14

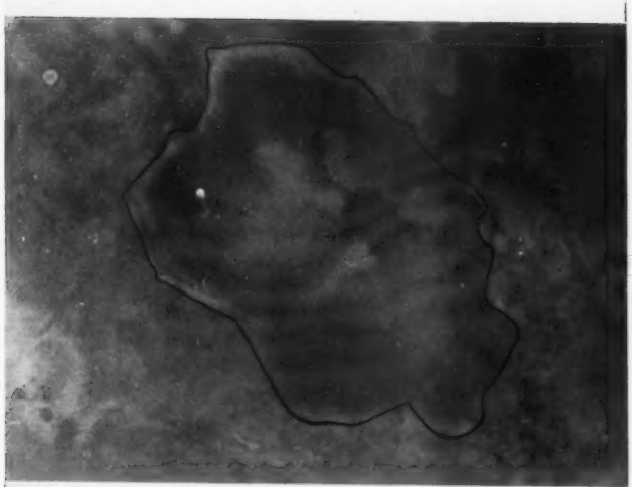


Figure 15

FIG. 14.—Minute inclusion of dolomite in anhydrite grain. Enclosing grain is at extinction to make dolomite visible. Crossed nicols; magnification, 360 diameters.

FIG. 15.—Quartz rosette in massive anhydrite. Sulphur center, appearing dark. Crossed nicols; magnification, 360 diameters.

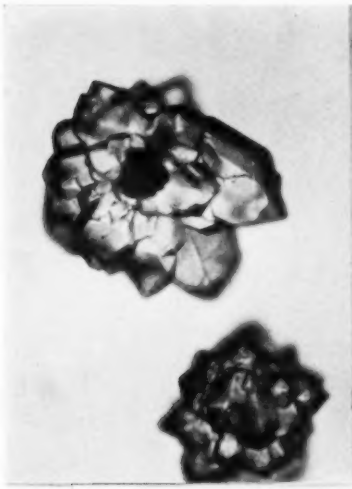


Figure 16

Figure 17

Figure 18

Figure 19

FIG. 16.—Quartz rosettes dissolved out of anhydrite and calcite. Sulphur centers, brilliant yellow in reflected light, dark in transmitted light and photograph. Mounted in hyrax. Plane polarized light; magnification, 80 diameters.

FIG. 17.—Dolomite rhombs and quartz rosettes dissolved out of specimen of calcite. Plane polarized light; magnification, 26 diameters.

FIG. 18.—Quartz rosette in calcite groundmass. Perfect median section, showing center of sulphur. Crossed nicols; magnification, 80 diameters.

FIG. 19.—Artificial solution residuals of anhydrite. Notice characteristic double wedge shape. Plane polarized light; magnification, 80 diameters.

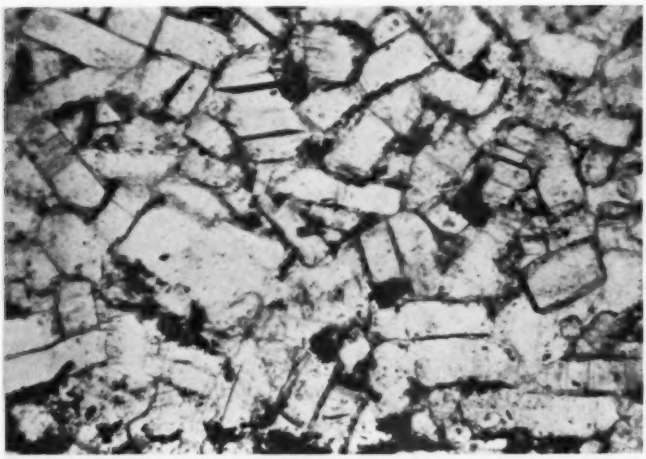


Figure 20

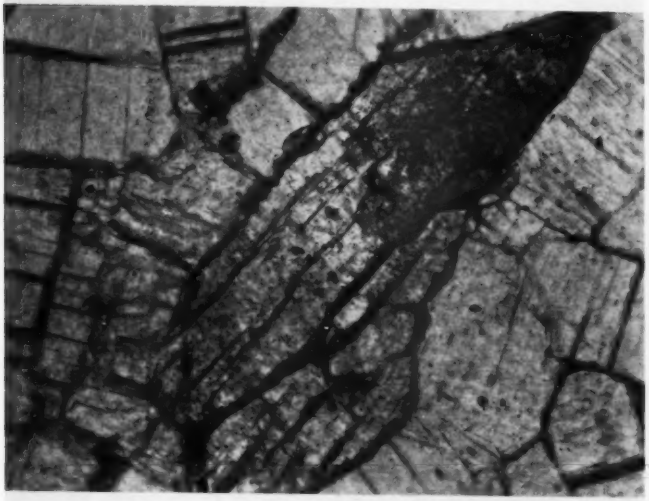


Figure 21

FIG. 20.—Massive unaltered anhydrite, showing "pile-of-brick" structure. Plane polarized light; magnification, 26 diameters.

FIG. 21.—Massive unaltered anhydrite, showing large grain of syngenetic celestite. Plane polarized light; magnification, 80 diameters.

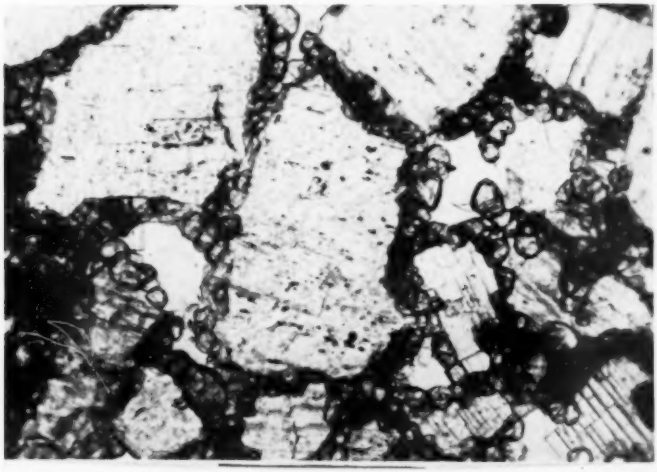


Figure 22

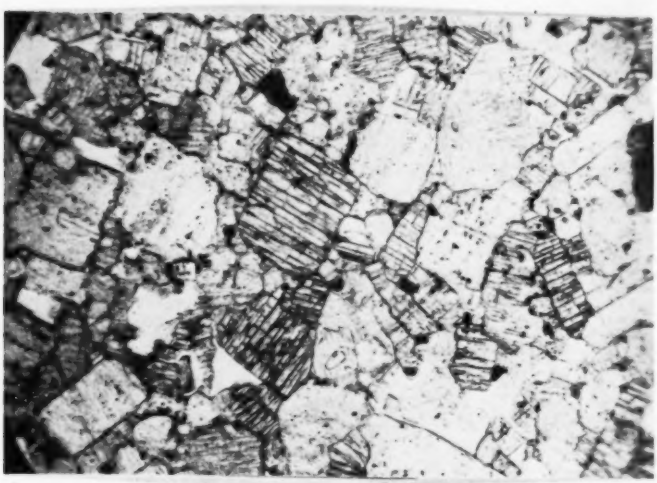


Figure 23

FIG. 22.—Massive anhydrite, showing calcite interstitially forming "net" structure in early stages of carbonate alteration. Plane polarized light; magnification, 80 diameters.

FIG. 23.—Massive unaltered anhydrite. Plane polarized light; magnification, 26 diameters.

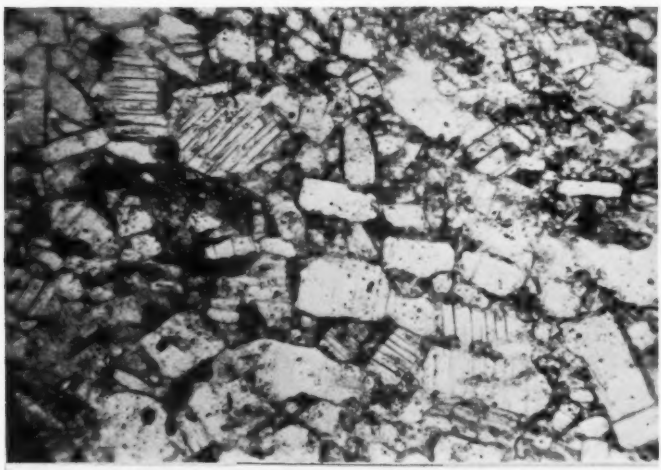


Figure 24

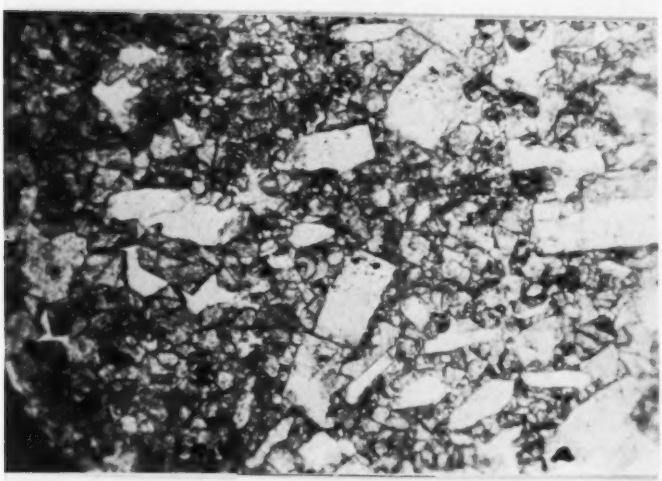


Figure 25

FIG. 24.—Massive anhydrite, in early phase of carbonate alteration. Plane polarized light; magnification, 26 diameters.

FIG. 25.—Massive anhydrite in considerably advanced stage of carbonate alteration. Plane polarized light; magnification, 26 diameters.

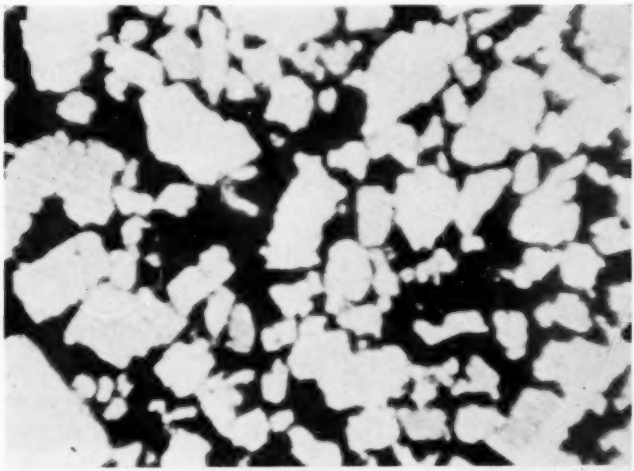


Figure 26

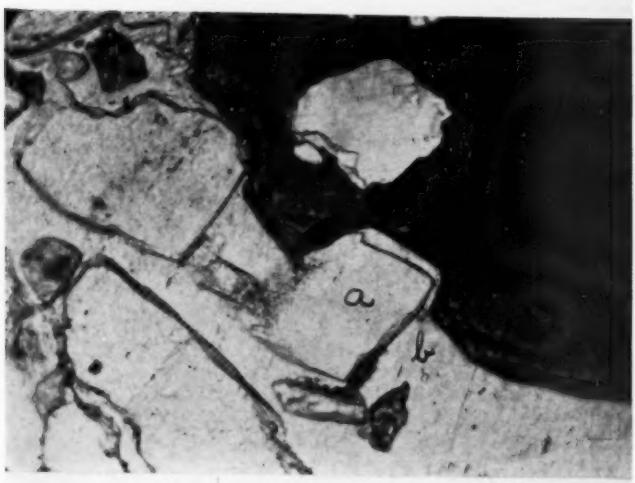


Figure 27

FIG. 26.—Massive anhydrite embedded in sulphur (dark). Plane polarized light; magnification, 26 diameters.

FIG. 27.—Anhydrite altering to gypsum. (a) Anhydrite grain. Dark area is sulphur. (b) Gypsum, single crystal of selenite extending throughout field. Notice narrow stringer entering between anhydrite and sulphur, and parallel borders of these two minerals. Plane polarized light; magnification, 80 diameters.

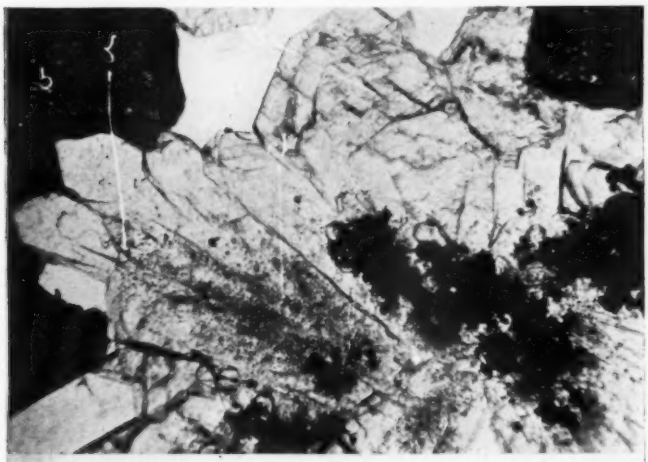


Figure 28

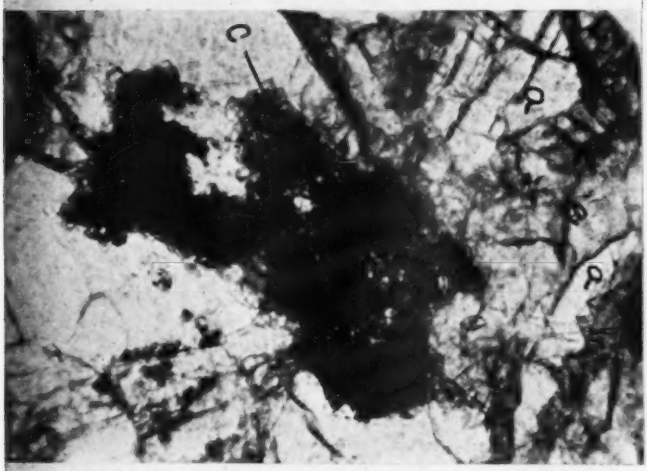


Figure 29

FIG. 28.—Sulphur (b), dark, later than secondary celestite (a) in perfect radiating crystals, which encloses many fine particles (c) of flocculent material resembling sulphur. Plane polarized light; magnification, 80 diameters.

FIG. 29.—(a) Former single crystal of celestite now separated by carbonate (e); (b) hazy, yellow, flocculent material resembling sulphur; (c) black, cryptocrystalline material. Plane polarized light; magnification, 80 diameters.

formation; (b) I do not accept Glen Rose or any other age as adequately indicated.

3. We tend to differ as to the origin of the sulphur and calcite of the calcite cap. Professor Brown is inclined to regard the sulphur in the calcite cap as derived from syngenetic sulphur in the underlying anhydrite cap, and the calcite from ordinary ground waters. I am inclined to believe that practically all the sulphur throughout the cap (anhydrite, gypsum, calcite, and "false" cap) and essentially all the calcite, are derived from reduction of calcium sulphate by hydrocarbons at the edge of the gypsum anhydrite cap, with subsequent transportation into the cap in solution, and deposition there by replacement, or in openings where openings happened to be available.

As a minor point I would not specify whether the waters in which the original anhydrite was deposited were marine or inland. In either case the conditions of deposition were not normal marine conditions.

On most observational facts we agree.

I have not carried my studies of calcite cap rock beyond those reported in my 1925 paper. Professor Brown's conclusion that all of the *true* calcite cap is derived from the gypsum anhydrite cap seems to me important. The specimens of calcified sedimentary rocks that I studied were probably from the "false" cap. We probably have, therefore, the following as a typical sequence.

"False cap" equals calcified sediments originally overlying the gypsum anhydrite cap

True calcite cap equals calcified gypsum anhydrite cap, free from all detrital or gritty material, as Professor Brown points out

Gypsum cap where present
Anhydrite cap
Zone of brine or *tight contact* with
Salt

LEVI S. BROWN, Austin, Texas: Although I appreciate the time and interest shown, nevertheless I do not feel that the preceding discussions of the "residual" theory are entirely relevant. I am glad that on "most observational facts" Dr. Goldman and I are in agreement, but the discussions do not show wherein the petrographic deductions are in error, or how the facts observed support the residual theory. In a later paper evidence will be assembled supporting my objections to the latter, as applied to American domes, though its value in explanation of the German structures is evident.

As to the anhydrite breccia mentioned by Dr. Goldman in his discussion and in his 1925 paper, I have seen many times what I believe to be the structure described. In polished sections a brecciated appearance can not be denied, and Dr. Goldman's conclusions seem to be based largely on examination of polished sections. On minute examination, however, I am unable to distinguish petrographically or mineralogically between the fragments and the "recrystallized matrix," except that the fragments show greater evidence of physical distortion. These areas appear whiter than the "matrix" because of granulation in movement, and the "apparently stratified" structure to me is the resulting gneissic texture described in my paper. Therefore I can not "accept this distinction;" also, I have not been able to recognize any petrographic evidence of "recrystallization" of the anhydrite.

I am familiar with the Hockley structure, and have studied the salt-anhydrite contact in detail as seen in the mine shaft. The horizontal banding and narrow salt-bearing transition zone parallel with the contact are well exemplified. To me the contact is an excellent illustration of a change of facies in a conformable series, and the presence of small quantities of the opposite mineral through a short distance on each side of the contact is to be expected. To assign this horizontal banding to solution, and to regard the transition border as one in which the "removal of the salt. . . . is not yet complete," to my mind introduce an unnecessary and very complicating factor, and Dr. Goldman desired to leave "out of the discussion the difficult question of the origin and circulation of waters" capable of producing such solution.

The sulphur problem in this paper is of secondary consideration. I have presented only such data as could not be omitted in a discussion of cap rock. Considerably more is available that I plan to incorporate in a later paper on sulphur genesis. The "strong implication" suggested by Dr. Goldman seems almost conclusive, but I am unwilling to accept it without more positive and direct petrographic evidence. I have observed sulphur in anhydrite unattended by calcite, and calcite commonly occurs plentifully in the altering anhydrite without the appearance of sulphur. I concede that origin through reduction by hydrocarbons is possible, but direct proof that reduction has occurred is lacking. I presented and illustrated three petrographic structures that to me prove some of the sulphur present in the anhydrite as such prior to the entry of any altering solutions, but on these Dr. Goldman presented no comments.

The uniform appearance of syngenetic celestite in all of the anhydrite caps to me militates strongly against the residual theory. Whether it proves Glen Rose age or not is immaterial. I agree that such indication is not entirely conclusive, but must reassert it as an observed petrographic fact that could have that significance. It was offered in the hope that other workers in known Permian or Comanche anhydrites would collaborate in determining its value in this regard. At present no contrary evidence has appeared, and I think it merits detailed consideration.

There is some evidence that the language in the original paper is not entirely clear, and I regret that space will not permit clarification. It is possible also that I have misconstrued part of the discussion; if so, I hope I may be extended pardon.

F. H. LAHEE, Dallas, Texas: I should like to make the suggestion that investigators of cap-rock material should also study and analyze the underlying salt. There may very well be a genetic relation between the two. For this reason, inferences and theories based on an examination of the cap rock, unless supported by evidence from the salt, may perhaps be in error.

DONALD C. BARTON, Houston, Texas: This paper is a notable contribution to the geology of the salt-dome cap. With regard to nearly all of the argument, I have no adverse criticism to offer, but I would like to express the adverse comment that the evidence for the suggested Glen Rose age of the anhydrite of the cap is rather scanty and insufficient. I understand that, as yet, Professor Brown has not had the time to carry his detailed study to consideration of the Lower Cretaceous anhydrite and the Permian anhydrite.

Correlation of the cap-rock anhydrite with the Glen Rose on the basis of the common occurrence of celestite seems unsafe until the evidence is clear that the Permian anhydrite does not also equally contain celestite or/and that celestite is not common in general in sedimentary anhydrite deposits. The Lower Cretaceous anhydrite of northwest Louisiana has been seen by me only in a small suite of cores; in all the cores the anhydrite had a chalcedonic aspect and no megascopic crystalline structure. The cap-rock anhydrite of the north Louisiana domes, however, is the characteristic saccharoidal cap-rock anhydrite. The Permian anhydrite of the Toyah area of the West Texas Permian basin is a saccharoidal anhydrite very similar in megascopic aspect to the cap-rock anhydrite, except in leaving pronounced "Jahresringe" banding.

The salt and the anhydrite in the Lower Cretaceous of southwest Texas are additional facts which must be weighed as possible evidence of the Lower Cretaceous age of the salt and anhydrite in the salt domes, but in Germany salt occurs in the Tertiary as well as in the Permian. Until some definite evidence of their age is found in the anhydrite and/or salt, it is unsafe to conclude that the mere presence of salt and anhydrite in the Lower Cretaceous of Texas necessarily means that the salt and anhydrite of the salt domes are of Lower Cretaceous age.

Professor Brown has made an admirable start on the problem of the cap. I rather suspect that a continuation of this study may reveal fairly good evidence for the correlation of the anhydrite of the cap rock either with the Lower Cretaceous or the Permian anhydrite. I sincerely hope that Professor Brown will continue his studies and that geologists will coöperate with him by the contribution of samples which may be of service to him.

TERTIARY HISTORY OF REGION OF SABINE UPLIFT, LOUISIANA[1]

C. L. MOODY[2]
Shreveport, Louisiana

ABSTRACT

The Sabine uplift, the most prominent structural feature of the Gulf Embayment region, centers in northwestern Louisiana. This area of structural unrest underwent a long and complicated history in Mesozoic time, but its present characteristics were not completed until the end of Miocene deposition. The dawn of Tertiary time showed a widespread advance of the waters of the Midway sea. Remarkably stable conditions of the earth's crust prevailed during the deposition of 600 feet of black shaly clay on a heterogeneous Cretaceous floor. Subsequent depositional history is traced in continual and widespread advances and retreats of the gulf waters. During the deposition of the beds of the Wilcox group the Sabine uplift region was slowly rising. Twice during Claiborne time the gulf withdrew almost to its present limits. Eocene deposition closed with the withdrawal of the extensive Jackson sea. Oligocene deposits were laid down in a contracting gulf and the succeeding Miocene beds are largely continental in character.

The existing folds, faults, and salt domes were formed immediately following the completion of Miocene deposition. The gulf then receded far beyond the present shore line, erosion became active, and the Tertiary period closed with the entire region deeply covered with a mantle of Pliocene sand and gravel. Quaternary time has been largely consumed in the removal of this débris.

It is suggested that the origin of the disturbance is related to the development of the ocean deep now occupied by the Gulf of Mexico and that its details are the result of the lateral migration of molten material deep in the underlying crust of the earth.

INTRODUCTION

This paper is written in the belief that a statement of the major events in the later history of the region of the Sabine uplift, particularly the establishment of the relations of sea and land during Tertiary time as interpreted from the record preserved in the sediments, might be of some interest to present workers in Coastal Plain geology. The facts on which the ensuing discussion is based are widely known; many of them have been published and some of the important ones, especially those which have been discovered in the exploitation of the Louisiana-Arkansas oil fields, are in possession of the oil companies but have not yet been made a part of the published geologic record. The writer has drawn upon the

[1]Presented before the Association at the New Orleans meeting, March 20, 1930. Manuscript received, January 26, 1931.

[2]Ohio Oil Company.

small supply of unpublished facts as freely as upon the great store of published data in reaching the conclusions here set forth.

Much field study has been devoted to the Mississippi Embayment area by the Coastal Plain geologists, special emphasis in recent years having been placed on detailed mapping of the Tertiary formations. Needless to say, the older maps have been completely revised, but few indeed have been the changes found necessary in fundamental ideas of stratigraphy propounded by the pioneers in this difficult province. The modern investigator, equipped with plane table, microscope, and plotted log and having the facilities of present-day transportation at his command, has added a few details omitted by his illustrious predecessors, but the firm foundation which supports his elaborate structure contouring was laid in the early work of Harris, Veatch, Vaughn, Smith, Kennedy, and Dumble, reinforced by the later labors of such earnest scientists as Stephenson, Berry, Matson, Hopkins, Powers, and Cooke.

SABINE UPLIFT

The term "Sabine uplift" was introduced by G. D. Harris[1] in his discussion of the Louisiana oil fields, in which he shows by a sketch map and explanatory note that northwestern Louisiana and a part of East Texas have been affected by extensive crustal movements which were "of prime importance in oil and gas concentration." He had previously used the term "Sabine peninsula" for the same structural feature shown on the tectonic map which accompanies his discussion of the salt deposits of Louisiana and Texas.[2]

In Veatch's monumental work on the water supply of northern Louisiana and the adjacent part of Arkansas,[3] no mention is made of the Sabine uplift, but his cross sections clearly indicate his early recognition of crustal uplift in this area.

Certain details of structure of parts of the Sabine uplift appear in the maps and sections accompanying the reports of Matson and Hopkins on the Caddo and De Soto-Red River oil fields of Louisiana,[4] but the first comprehensive discussion to be found is in the excellent paper by

[1] G. D. Harris, "Oil and Gas in Louisiana," *U. S. Geol. Survey Bull. 429* (1910), map, p. 27, Fig. 1.

[2] *Idem*, "Rock Salt," *Geol. Survey of Lousiana Bull. 7* (1908), Pl. 24.

[3] A. C. Veatch, "Geology and Underground Water Resources of Northern Louisiana and Southern Arkansas," *U. S. Geol. Survey Prof. Paper 46* (1906), Pl. 37.

[4] G. C. Matson, "The Caddo Oil and Gas Field, Louisiana and Texas," *U. S. Geol. Survey Bull. 619* (1916).
G. C. Matson and O. B. Hopkins, "The De Soto-Red River Oil and Gas Field, Louisiana," *U. S. Geol. Survey Bull. 661 C* (1918).

Sidney Powers.[1] To this paper the reader is especially referred for the outlining of the pre-Tertiary history of the Sabine uplift and for an interesting theory to explain the origin of the disturbance.

The structure of the Cretaceous formations affected by the Sabine uplift has been shown by means of structure-contour maps published by Huntley and Spooner.[2]

It was clearly Professor Harris' intention to apply the term "Sabine uplift" to the area of high Cretaceous structure centering in northwestern Louisiana. Powers[3] limits the area to be included in the uplift to that lying within the 1,000-foot contour as drawn on the top of the Nacatoch sand (Upper Cretaceous). Huntley[4] takes exception to the narrow confines assigned to the Sabine uplift and would include the Homer and Monroe uplifts as parts thereof. Though his conclusions were founded on an inadequate map, they are supported to some extent by later investigations.

The crustal disturbance which perfected the Sabine uplift affected the whole of northern Louisiana, most of East Texas, much of the Coastal Plain area of Arkansas, and the entire Coastal Plain of Mississippi and Alabama. The maximum deformation occurred in north Louisiana and south Arkansas. The entire area lying north of the Angelina-Caldwell monocline[5] and between the Arkansas and Tyler synclines (Fig. 5) had essentially the same Tertiary history. If we glance at Mesozoic history, we find that the eastern part of the area centering in the gas-producing territory in the vicinity of Ouachita River suffered more early deformation than did the Shreveport area. Throughout Tertiary time, north Louisiana and adjacent parts of Arkansas and Texas were clearly a structural unit. The Sabine uplift as limited by Powers is merely the area of maximum deformation on a structural terrace of vastly greater size.

The Sabine uplift had its beginning at least as early as the commencement of Cretaceous time; its Mesozoic history was long and com-

[1]Sidney Powers, "The Sabine Uplift, Louisiana," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 4, No. 2 (1920), pp. 117-36.

[2]L. G. Huntley, "The Sabine Uplift," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 7, No. 2 (1923), p. 180.
W. C. Spooner, "Interior Salt Domes of Louisiana," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 10, No. 3 (March, 1926), Pl. 12.

[3]*Op. cit.*, p. 119, Fig. 1.

[4]*Op cit.*, p. 179.

[5]A. C. Veatch, *op. cit.*, p. 68.

plex, its Tertiary history scarcely less so. To gain an insight into the course of events that brought about conditions as we find them to-day in north Louisiana, it is necessary to review the record of happenings not only in Louisiana, but also in that larger part of the Gulf Coastal Plain known as the Mississippi Embayment. It is in this sense that the "region of the Sabine uplift" is to be understood in the ensuing discussion.

AREAL GEOLOGY

The generalized areal map (Plate 1) which accompanies this paper has been compiled from five sources, as follows: (1) the State Survey map of Alabama,[1] (2) the areal map of Mississippi accompanying the recent water-supply paper for that state,[2] (3) the new State Survey map of Arkansas,[3] (4) the small map accompanying Matson's report on the clays of Louisiana,[4] and (5) the writer's own unpublished maps of southwestern Arkansas, northern Louisiana, and East Texas.

With one exception, the cartographic units chosen for delineation on the map correspond with the major subdivisions of Coastal Plain geology. The Cockfield formation, because of its importance in portraying the eastward extent of the Sabine disturbance, was separated from the remaining divisions of the Claiborne group. Its age is Upper Claiborne. The Wilcox area, shown between Little Rock and Ouachita River, includes the lower sands of the Claiborne group; the Claiborne line as drawn in this territory is essentially the Mount Selman-Queen City contact.

This map indicates in a general way the limits of the area disturbed by the forces which culminated in the Sabine uplift. The center of the disturbance is to be found in the great inlier of Wilcox formations in northwestern Louisiana and East Texas. The Tyler syncline can be inferred from the continuity of the Claiborne formations north of Marshall, Texas. The steep southerly dip limiting the uplift in that direction, as pointed out by Veatch,[5] is clearly discernible in the narrow belts of outcrop extending across central Louisiana; and the northeasterly dip

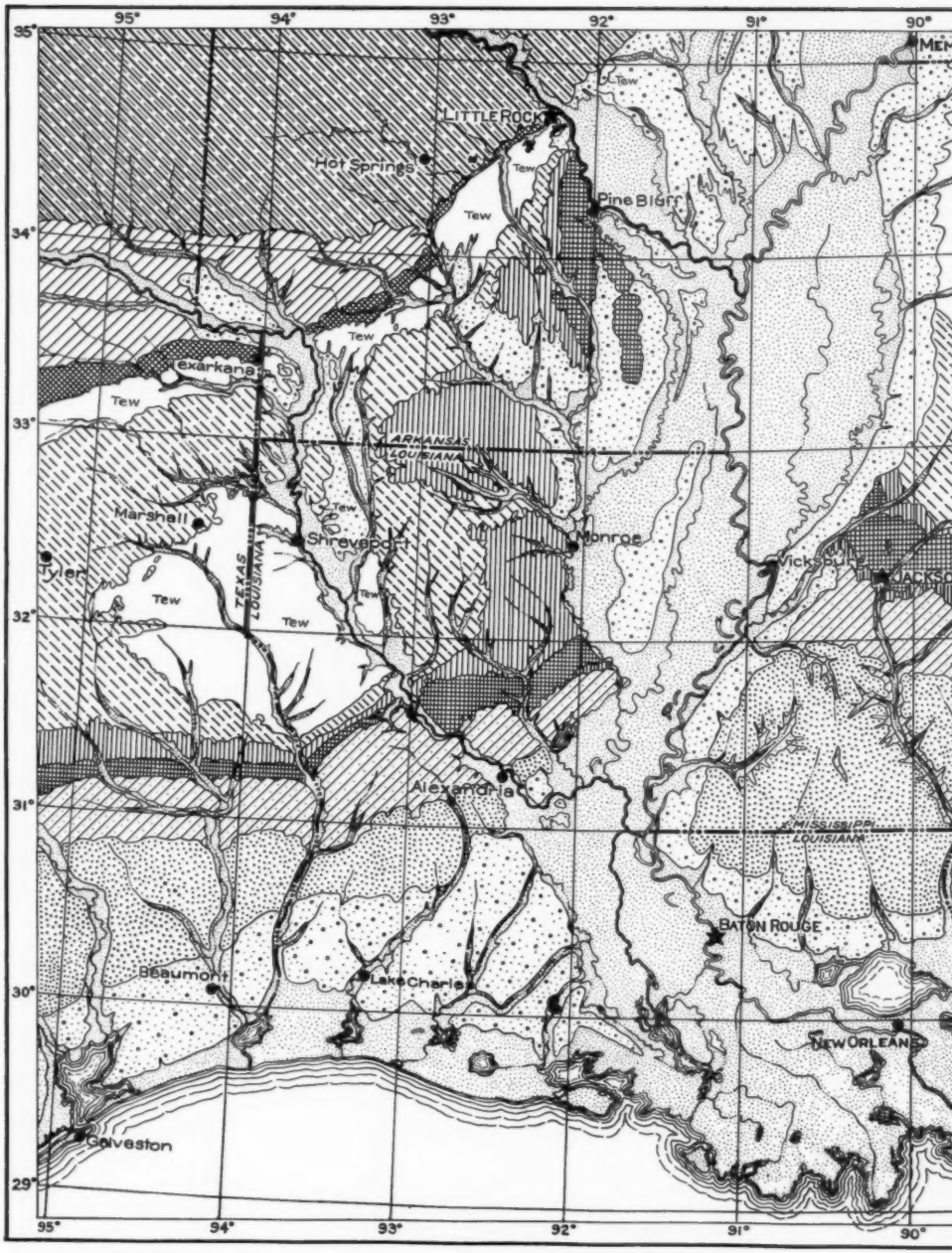
[1]G. I. Adams, Charles Butts, L. W. Stephenson, and Wythe Cooke, "Geology of Alabama," *Geol. Survey of Alabama Special Pub. 14* (1926).

[2]L. W. Stephenson, W. N. Logan, and G. A. Waring, "The Ground Water Resources of Mississippi," *U. S. Geol. Survey Water Supply Paper 576* (1928).

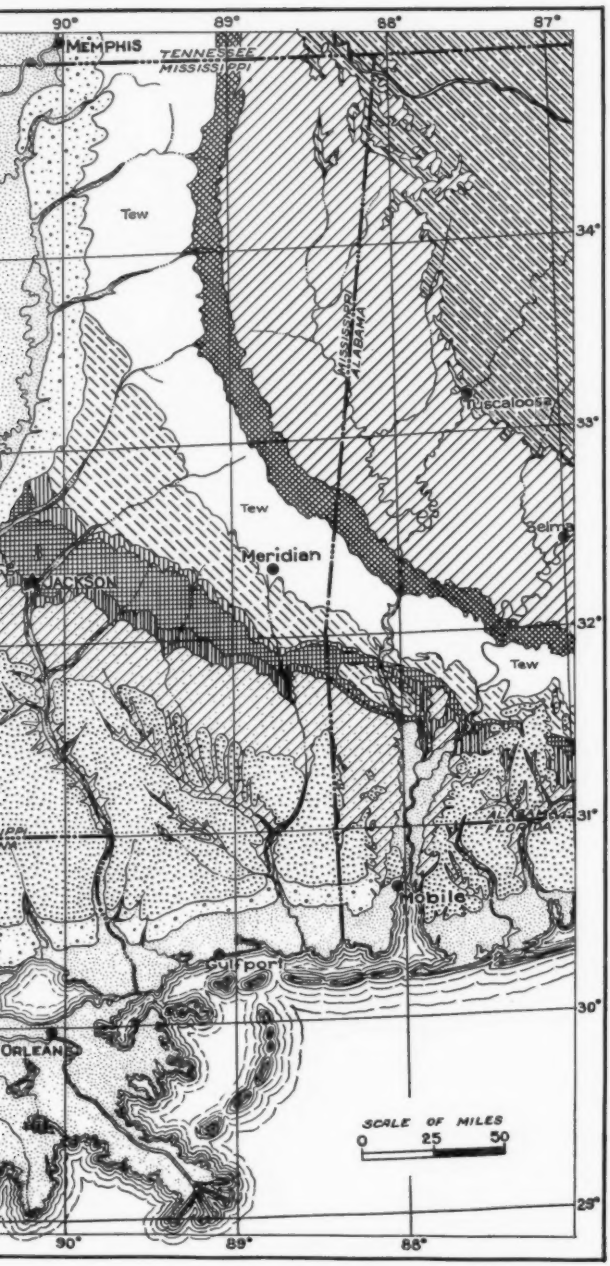
[3]G. C. Branner and others, "Geologic Map of Arkansas," *Arkansas Geol. Survey* (1929).

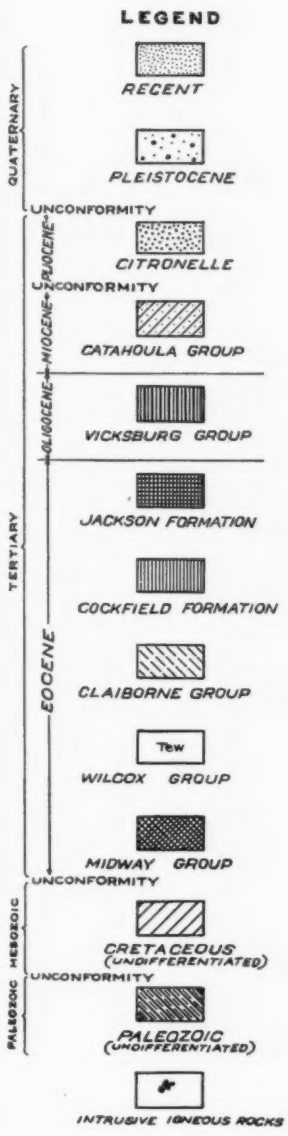
[4]G. C. Matson, "Louisiana Clays," *U. S. Geol. Survey Bull. 660-E* (1917), Pl. 5.

[5]A. C. Veatch, *op. cit.*



Geologic map of Mississippi, Louisiana, and adjacent part





adjacent parts of Texas, Arkansas, and Alabama.

into the Arkansas syncline is just as certainly indicated by the strike of the Jackson formation south of Pine Bluff. The Crowley's Ridge outcrops of Jackson, which could not be shown on the map because of cartographic difficulties, suggest a width of nearly two degrees of longitude for this basin in the latitude of Little Rock.

The area which was positively elevated in the completion of the Sabine uplift, exclusive of the related parts of Mississippi and Alabama, is conservatively estimated at 19,000 square miles.

CORRELATIONS

The accompanying table of correlations of the Tertiary formations of East Texas, Louisiana, and Arkansas with those of Mississippi and Alabama (Table I) rests on a secure paleontologic foundation and, with the exception of the subdivisions of the Claiborne group, needs no discussion in its adaptation to the writer's purposes in this paper.

Claiborne nomenclature is at present in a somewhat chaotic condition, caused in part by the inherent difficulties connected with detailed correlation within the group and in part by the practice of limiting formations by state boundaries. It is not the purpose of the writer to enter into an exhaustive discussion of the literature of the Claiborne group, for that has been ably accomplished in Miss Ellisor's recent paper on Claiborne correlation,[1] nor to approach the controversial side of the subject with any thought other than that of simplification.

The writer's correlations are based on his having traced the *Ostrea sellaeformis* fauna across the state of Mississippi, and mapped the containing strata in detail in Louisiana and in a reconnaissance way in Arkansas and Texas. The assurance that the physical facts had been obtained and that the proper conclusions had been drawn therefrom did not, however, solve the problem of a choice of name for the containing formation. In Alabama the formation is the upper part of the Lisbon of Smith;[2] in Mississippi it is the Wautubbee marl of Lowe;[3] in Louisiana it has been called St. Maurice by Harris and others,[4] St. Maurice "restricted" by Spooner,[5] and "Minden" and "Jonesboro" in oil company

[1] A. C. Ellisor, "Correlation of the Claiborne of East Texas with the Claiborne of Louisiana," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 13, No. 10 (October, 1929), pp. 1336-39.

[2] E. A. Smith and others, "Report on the Geology of the Coastal Plain of Alabama," *Alabama Geol. Survey* (1894).

[3] E. N. Lowe, *Mississippi State Geol. Survey Bulletins 12 and 14* (1915 and 1919).

[4] G. D. Harris, *op. cit.*

[5] W. C. Spooner, *op. cit.*, p. 237.

TABLE I

PROVISIONAL CORRELATION OF TERTIARY FORMATIONS OF EAST TEXAS, LOUISIANA, AND ARKANSAS, WITH MISSISSIPPI AND ALABAMA

			EAST TEXAS	LOUISIANA and ARKANSAS	MISSISSIPPI	WESTERN ALABAMA
QUATERNARY	RECENT		Alluvium; marsh and beach deposits	Alluvium; marsh and beach deposits	Alluvium; beach sands	Alluvium, beach sands
	PLEISTOCENE		PORT HUDSON; BEAUMONT CLAY	PORT HUDSON; BEAUMONT; loess	PORT HUDSON; loess	High stream and beach terraces
TERTIARY	PLIOCENE		CITRONELLE	CITRONELLE	CITRONELLE	CITRONELLE
	MIOCENE		FLEMING CATAHOULA SANDSTONE	FLEMING CATAHOULA SANDSTONE	PASCAGOULA HATTIESBURG CATAHOULA SANDSTONE	PASCAGOULA HATTIESBURG
	OLIGOCENE		(Overlapped)	VICKSBURG GROUP	VICKSBURG GROUP BYRAM MARL GLENDON LIMESTONE MARIANNA LIMESTONE FOREST HILL - RED BLUFF	VICKSBURG GROUP BYRAM MARL GLENDON LIMESTONE MARIANNA LIMESTONE RED BLUFF CLAY
	EOCENE		JACKSON	JACKSON	JACKSON { YAZOO CLAY / MOODY'S BRANCH	JACKSON - OCALA LIMESTONE
		CLAIBORNE	COCKFIELD	COCKFIELD	COCKFIELD	COCKFIELD / GOSPORT
			COOK MOUNTAIN	COOK MOUNTAIN	WAUTUBBEE MARL	LISBON
			SPARTA SAND	SPARTA SAND	KOSCIUSKO SAND	
			MOUNT SELMAN	MT. SELMAN	WINONA SAND	
			QUEEN CITY SAND	QUEEN CITY / CANE RIVER		
			REKLAW	REKLAW	TALLAHATTA	TALLAHATTA
		WILCOX	WILCOX GROUP (UNDIFFERENTIATED)	WILCOX GROUP (UNDIFFERENTIATED)	GRENADA	HATCHETIGBEE
					HOLLY SPRINGS	BASHI / TUSCAHOMA
					ACKERMAN	NANAFALIA
		MIDWAY	MIDWAY (UNDIFFERENTIATED)	MIDWAY (UNDIFFERENTIATED)	TIPPAH SANDSTONE	NAHEOLA
					PORTER'S CREEK CLAY	SUCARNOCHEE
					CLAYTON	CLAYTON

reports and general conversation; has been divided into three members, Saline Bayou, Milams, and Crockett, by Miss Ellisor,[1] and recently has been christened Mount Lebanon in a well written contribution by Shearer.[2] In Texas the same beds have been called Cook's Mountain by Kennedy[3] and Dumble,[4] Lufkin by Renick,[5] and Saline Bayou, Milams, and Crockett by Miss Ellisor.[6] Cook Mountain is a term of long standing, has appeared in publications of the United States Geological Survey,[7] and was indicated by Harris as a subdivision of his St. Maurice.[8] For these reasons this term is here used for the formation which contains the *Ostrea sellaeformis* fauna in Texas, Louisiana, and Mississippi.

The Claiborne subdivisions of East Texas have been admirably described in a recent paper by Wendlandt and Knebel[9] in which the stratigraphic relations of the several formations are clearly set forth. In this and the companion paper by Miss Ellisor,[10] cogent reasons are advanced for the revival of the term Cockfield as a substitute for Yegua, though only the latter author actually makes the change. Throughout her interesting paper Miss Ellisor consistently refers to the subdivisions of the Claiborne series as "members," though Wendlandt and Knebel mention the same units as "formations." In the latter paper Cook Mountain and Mount Selman are used as sub-group names; Saline Bayou, Milams, Crockett, and Sparta as formations of the Cook Mountain sub-group; Weches, Queen City, Reklaw, and Carrizo as formations of the Mount Selman group; and the Yegua is given equal rank with the

[1]A. C. Ellisor, *op. cit.*, pp. 1339-40.

[2]H. K. Shearer, "Geology of Catahoula Parish, Louisiana," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 14, No. 4 (April, 1930), p. 439.

[3]William Kennedy, "A Section from Terrell, Kaufman County, to Sabine Pass on the Gulf of Mexico," *Geol. Survey of Texas 3d Ann. Rept.* (1891).

[4]E. T. Dumble, "Geology of the Brown Coal Deposits of Texas," *Geol. Survey of Texas* (1892), pp. 148-54.

[5]B. C. Renick, "Recently Discovered Salt Domes in East Texas," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 12, No. 5 (May, 1928).

[6]A. C. Ellisor, *op. cit.*

[7]A. Deussen, *U. S. Geol. Survey Water Supply Paper 335* (1914), and *U. S. Geol. Survey Prof. Paper 126* (1924).

[8]G. D. Harris, *op. cit.*, Pl. 12.

[9]E. A. Wendlandt and G. Moses Knebel, "Lower Claiborne of East Texas with Special Reference to Mount Sylvan Dome and Salt Movements," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 13, No. 10 (October, 1929), pp. 1350-61.

[10]A. C. Ellisor, *op. cit.*

sub-group divisions. This grouping obscures certain important facts of geologic history, according to the writer's interpretation, and, though realizing that there are almost insuperable difficulties in establishing a consistent, logical classification of the Claiborne group, he believes that the facts are better portrayed in considering the subdivisions of East Texas as formations of equal rank. Reasons have already been advanced for the adoption of the term Cook Mountain. Believing that the time-honored name Mount Selman should be perpetuated, he has, for present purposes, returned it to good standing at the expense of the Weches of Wendlandt and Knebel. The Reklaw, as defined in their paper,[1] is considered by the writer as the basal Claiborne formation of Texas; it properly includes the Omen member, which is therein assigned to the Queen City sand. The essential continuity of the unique lithology of the Tallahatta formation from Alabama River to San Augustine, Texas, and the remarkably wide distribution of the *Ostrea sellaeformis lisbonensis* fauna which has been traced from Lisbon Landing on Alabama River, through the Winona sand of Mississippi and the Cane River formation of Louisiana to the Mount Selman of Texas, constitute the important evidence on which the correlation of the early Claiborne rests.

TERTIARY HISTORY

Early Eocene deposition.—It has been known for many years that a long period of time elapsed between the termination of Cretaceous deposition and the accumulation of the earliest Tertiary deposits. The evidence has been largely paleontologic. Recent drilling in eastern Louisiana and central Mississippi has, however, furnished remarkable physical evidence of the reality of this hiatus. Development of the Richland gas field has shown that the basal Tertiary lies on an erosional surface in which strata ranging in age from late Cretaceous to early Comanche have been truncated to form the floor on which the deposits of the Midway sea were built up. On the Jackson anticline in Mississippi the Midway lies on early Cretaceous beds and in Sharkey County the same formation lies directly on igneous rock of andesitic composition the age of which is unknown. This heterogeneity of the floor over which the waters of the Midway sea were spread points clearly to a complex history in the time intervening between the cessation of Mesozoic deposition and the return to marine conditions at the dawn of Tertiary time.

Great likeness exists between the sedimentary material of the basal Tertiary and the latest Cretaceous. The dark, steel-gray, shaly clays of

[1] E. A. Wendlandt and G. M. Knebel, *op. cit.*, p. 1352.

which the Midway is largely composed, closely resemble the fine sediments of the Navarro of Texas, the Arkadelphia of Arkansas, and certain phases of the Ripley-Selma of Mississippi and Alabama. The lower part of the Midway group is chiefly calcareous, with true chalk occurring as lenses in Arkansas and Louisiana, which lenses are doubtless transitional from the Clayton limestone of the Alabama section to the Tehuacana limestone of northeast Texas. This calcareous Midway contains a well known marine invertebrate fauna. In later Midway time, limy material reached the sea in less and less quantity until only finely divided terrigenous detritus was deposited. Marine life also became gradually more impoverished and finally ceased to exist in the embayment region. It is noteworthy that siderite concretions were formed in profusion in the dark Midway clays. Their occurrence marks the end of the great Cretaceous cycle of calcareous deposition in the Gulf Embayment region and may be considered as inaugurating the period of iron deposition which culminated in the Claiborne. Two important conclusions may safely be drawn from a study of the physical character of the Midway beds: (1) the materials of the Midway and of the late Cretaceous formations were derived from essentially the same source under similar climatic and topographic conditions; (2) during Midway time the earth's crust was remarkably stable throughout hundreds of thousands of square miles in the Gulf Coastal Plain, being slowly and uniformly depressed while 600 feet of homogeneous mud was accumulating on the sea floor. Cessation of this crustal stability brought Midway deposition to a close and forced the Gulf shore line back toward the continental shelf.

When sedimentation was renewed the type of material furnished the depositional basins was greatly changed. Light gray clays and medium-grained sands gradually replaced the black shaly clay type of sediment, and the formation of glauconite, which had been common during the deposition of the arenaceous Cretaceous sediments, was renewed on the sea floor. Volcanic eruptive activity, which had contributed to the early Midway sea a thin stratum of ash, later altered to bentonite, supplied a small amount of ashy material, which was incorporated in the Wilcox sediments. The strand line, which had been stationary during the preceding Midway time, became a veritable will-o'-the-wisp, oscillating rapidly not only toward the continental border, but laterally as well, and the area which is now included in northern Louisiana and central Mississippi began slowly to rise relative to the surrounding sea floor. This movement was differential, resulting in the individualizing in early Wilcox time of the pronounced folds, both local and regional,

which characterize the Gulf Embayment area. The accompanying map (Fig. 1) shows the great variation in the total thickness of sediment of Wilcox age which accumulated in the embayment states. The areas of thick Wilcox deposition correspond exactly with the two major synclines and the gulfward monocline; the areas in which Wilcox deposits are thin include all the known structural "highs."

The correlation of this period of crustal unrest in the Coastal Plain with the Laramide revolution of the Cordilleran region is intriguing, but probably carries us too far afield even for a paper with the general scope of this one. It is evident that the Eocene structural disturbances are not related to a renewal of deformation in the region affected by the Appalachian revolution, for they are of least effect in southern Alabama, where the Appalachian complex had been buried by Mesozoic and early Eocene deposition, and in central Arkansas, where the deformation consisted only of gentle downwarping.

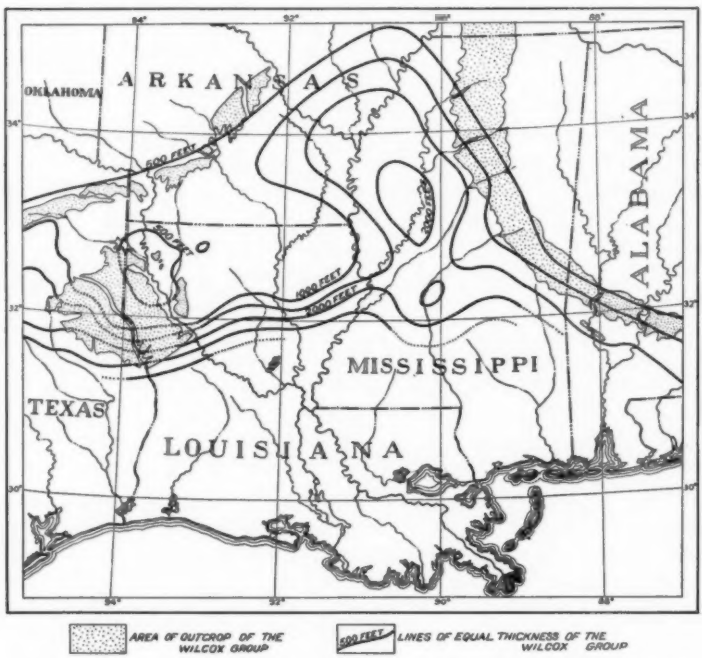


FIG. 1.—Map showing variation in thickness of sediment of Wilcox age in embayment states.

Much of the sedimentation of Wilcox time transpired under lagunal conditions. Lignite and carbonaceous clays especially characterize the continental formations of this age. The shore line of the Gulf extended only slightly north of the 33d parallel of latitude at its maximum expansion in late Wilcox time, but the non-marine deposits completely filled the Mississippi embayment to its northernmost limit.

Eocene paleogeography.—Throughout Tertiary time the extreme crustal stability of the Alabama Coastal Plain contrasts markedly with the relative mobility of the area near, and west of, the present Mississippi River, but this condition is especially emphasized when the paleogeography of the Claiborne group is considered. The record of Claiborne time in central Alabama is preserved in approximately 400 feet of terrigenous sediments, which have been divided into three formations with the classic Gosport sand at the top, the fossiliferous, glauconitic Lisbon in the middle, and the siliceous, sparingly glauconitic Tallahatta formation at the base. The Jackson marls lie directly on the Gosport sand at the type Claiborne locality, but a few miles farther west the lignitic Cockfield formation is found between the two. In central Mississippi the Gosport-Lisbon formation of Alabama has expanded into three well individualized formations which have received names as follows: Wautubbee marl at the top, and Winona sand at the base, with the non-marine Kosciusko sand in the intermediate position. With the Cockfield formation at the top of the Claiborne group and the Tallahatta at the base, the Mississippi Claiborne is divided into five formations with an aggregate thickness of 1,500 feet. In central Louisiana the Tallahatta and Winona sand are merged in the Cane River formation, the Kosciusko sand becomes the Sparta sand, and the Wautubbee marl has its equivalent in the Cook Mountain formation. In East Texas and northwest Louisiana the Cane River is expanded into three distinct formations, with the richly glauconitic Mount Selman at the top, the lignitic, sparingly ferruginous Queen City sand in the middle, and the glauconitic, argillaceous Reklaw at the base. This arrangement of formations is graphically shown in the ideal cross section (Fig. 2) and its origin is explained in the sketch map (Fig. 3) showing the approximate position of the shore line of the Eocene gulf at nine stages of its history.

Line 1 represents the maximum extent of the Midway gulf; its position is accurately known only in the central Arkansas region, where the remarkably straight Paleozoic escarpment which overlooks the Coastal Plain was early recognized as the northwestern boundary of marine transgressions in Cretaceous and later time. The igneous areas of outcrop in the vicinity of Little Rock formed islands in the Midway sea.

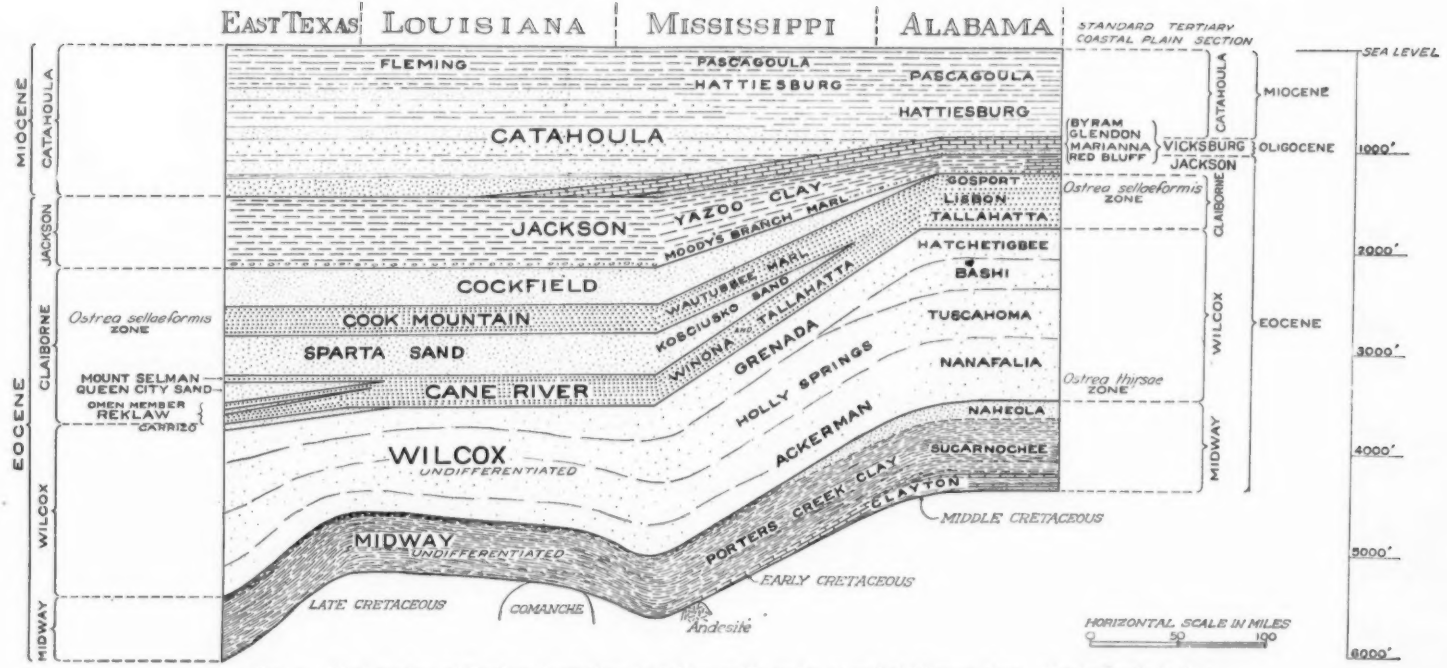


FIG. 2.—Ideal section of Tertiary formations in Sabine uplift region at end of Miocene time. Vertical scale in feet.

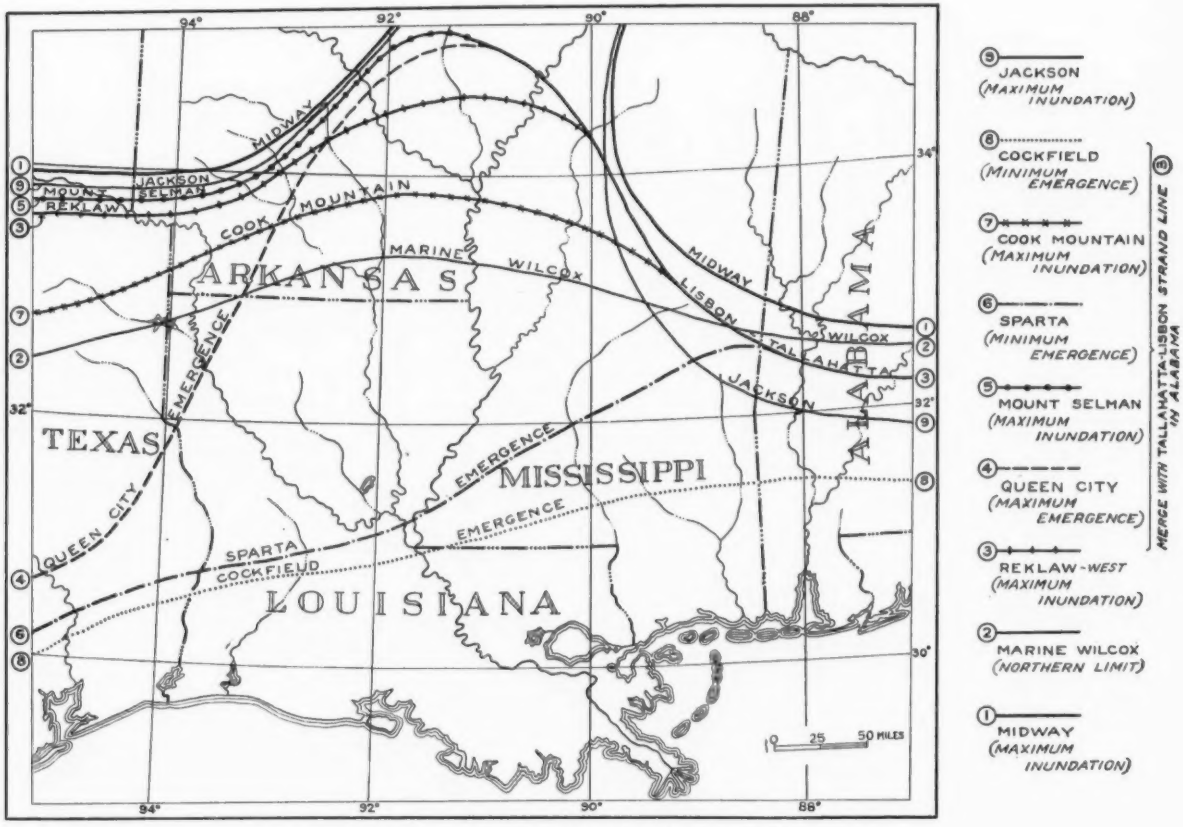


FIG. 3.—Eocene strand lines in Sabine uplift region.

Line 2 represents the present known northern limit of marine Wilcox deposition. This is not a definite shore line; it is believed that the exact outline of the early Wilcox strand line would be very irregular, probably following in a general way the configuration of the major structural features. The later Wilcox shore lines in Louisiana were parallel with Line 2, but did not reach much farther north than the 32d parallel of latitude.

Line 3 in the eastern part of the map denotes the upper limit of transgression of the Claiborne sea in Alabama and is termed the Lisbon-Tallahatta strand line; in the western part of the map this number denotes the northern extent of the Reklaw sea. The complete outline of the Claiborne gulf in the Mississippi Embayment region at its earliest stage is obtained by following Line 3 across the map. Reklaw deposition was brought to a close by an upwarping in East Texas and a concomitant downwarping of the Mississippi Embayment, resulting in a retreat of the gulf boundary to the position of Line 4. Landward from this line the Queen City sand was deposited under sub-aerial and fresh-water conditions, while seaward therefrom the deposition of glauconitic marine sediments, initiated in Reklaw time, proceeded uninterruptedly. After 200 or more feet of Queen City sand had accumulated, East Texas again passed beneath gulf level, the shore line moved northward to Line 5, and the existing non-marine sands were buried under 50 or more feet of astonishingly pure glauconitic sand which we now know as the Mount Selman formation. The next recorded event in the development of the Claiborne series was a broad, gentle uplift of that part of the sea floor lying west of the Alabama boundary, which drove the strand line at least as far south as the position of Line 6; the Alabama coast, however, remained relatively unchanged. A remarkable deposit of white sand accumulated on the landward side of this new shore line, burying the ferruginous sands and clays of the early Claiborne gulf to a depth of 500 feet; it is preserved for our observation in the Sparta sand (Fig. 4). We next find the land once more sinking and the gulf waters, teeming with invertebrate life, sweeping northward to Line 7. Between 100 and 400 feet of marls and ferruginous sands and clays were formed on the sea bottom. Countless tests and shells of marine organisms, having served their purpose to their makers, became incorporated in these sediments and, through the accident of exceptionally good preservation, many of them are to-day found in the paleontologic museums of the world; they are members of the *Ostrea sellaeformis* fauna which is characteristic of the Cook Mountain formation. A second upward movement of the sea floor,

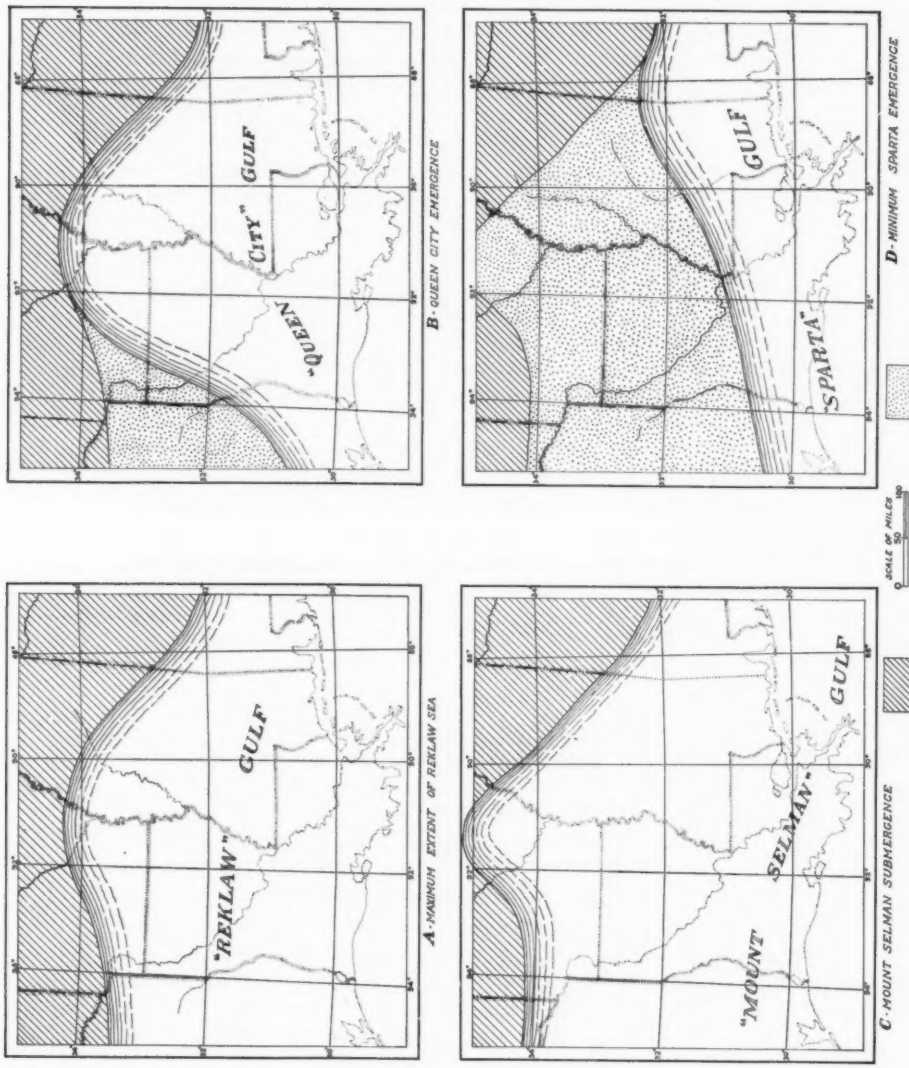


FIG. 4.—Paleogeography of Sabine uplift region in early Claiborne time.

this time affecting even the stable Alabama coast, brought an end to marine conditions, the strand line withdrawing to, or beyond, the position of Line 8. The deposition of the beds now known to us in the Cockfield formation, following in the wake of the retreating Cook Mountain sea, proceeded sufficiently rapidly, as had occurred also in the Queen City and Sparta emergences, to prevent the oxidation of the glauconite of the exposed marine deposits; they were buried in their original green condition beneath 200-600 feet of continental sands and clays. The third and final stage in the cyclic deposition of the Claiborne marine and non-marine formations in the vicinity of the 94th meridian was the first to occur on the Alabama shore, and its effect was not felt east of the area of the map. After a noteworthy erosional interval following Cockfield deposition in the Sabine uplift region, the gulf waters again flooded the Mississippi Embayment to its widest limits, and during a long period of comparative quiescence the deposits of the Jackson marine transgression were formed. In many respects the events of Jackson time which brought Eocene deposition to a close resemble the happenings of Midway or earliest Eocene time. The basal deposits preserved in each formation are very calcareous and contain plentiful remains of invertebrate organisms; progressive impoverishment of marine life and the very gradual upward transition into non-marine clay accumulation characterized both periods of deposition in the Mississippi Embayment region. From central Alabama eastward, however, the Jackson gulf was receiving only calcareous material, which, as has been shown by the work of Cooke, accumulated to form the Ocala limestone.

Neocene deposition.—The accumulation of limestone, initiated in the eastern gulf region in late Eocene time, the material of which must have been derived from the low-lying Appalachian province, progressed westward and dominated sedimentation during the Oligocene period, in which the well known formations of the Vicksburg group originated. Oligocene calcareous deposition was abruptly terminated by a sudden influx of coarse terrigenous detritus, which accumulated landward and in the margin of the rapidly retreating sea. In Louisiana and East Texas gentle downwarping of the Coastal Plain toward the west permitted the complete overlapping of the preceding marine Oligocene deposits by the coarse sands and mantling clays of the Miocene Catahoula formation. In the eastern gulf region marine conditions prevailed throughout Miocene time with clays and fine sands being deposited; west of Alabama the light-colored clays and coarse sands of the Catahoula accumulated under a marginal marine environment resembling in many ways the un-

settled conditions of Wilcox time. The cause of the sudden change from the calcareous deposition of Oligocene time to the arenaceous influx initiating Miocene sedimentation is to be sought in uplift of the region north of the central part of the Mississippi Embayment and not in a rejuvenation of the Appalachian area, as the coarse material was accumulated chiefly west of the Alabama line. Later Miocene deposition, represented by the calcareous clays of the Fleming formation and the eastern equivalents, the Hattiesburg and Pascagoula formations, occurred under definite lagunal and estuarine conditions probably much resembling the present depositional environment in coastal Louisiana.

Completion of the uplift.—The termination of Miocene sedimentation was accomplished by the initiation of a widespread elevation of the Mississippi Embayment, the first effect of which was the permanent banishment of the gulf waters toward the continental shelf. The shore line was probably considerably south of its present position before the culmination of the structural disturbances which were instituted at this time. The upward movement, following the limits outlined in Wilcox time, continued, raising successively the Miocene, Oligocene, and upper Eocene deposits of northern Louisiana and southwestern Arkansas into the sphere of active erosion, while the lateral synclinal areas in East Texas and northeastern Arkansas were further depressed and the gulfward dip of the monocline, now called the Angelina-Caldwell flexure, was accentuated. Uplift in north Louisiana was differential, resulting in net differences in elevation of as much as 2,000 feet between the Monroe terrace and the summit of the Bellevue dome, the culminating point of the Sabine uplift. The interior salt domes, like all the other major tectonic features of the region, had originated during Mesozoic time and had been accentuated during Wilcox deposition. Their upward movement was completed at this time by vertical thrust amounting to more than 3,000 feet in several places. Faults of moderate throw and with trend parallel with the Angelina-Caldwell monocline occurred during the uplift. The downthrown side of the more important of these faults was away from the central zone of uplift. Many local structural terraces, domes, and modified anticlines were completed in the territory between Sabine River of Texas and the Tombigbee of Alabama. Some of them at this time became the repositories of important gas and oil pools. The major structural features are indicated in Figure 5.

The soft, non-resistant Tertiary deposits in the zone of uplift were rapidly eroded and the region was shortly reduced to local base level. Abrupt rejuvenation of the highlands bordering the embayment then

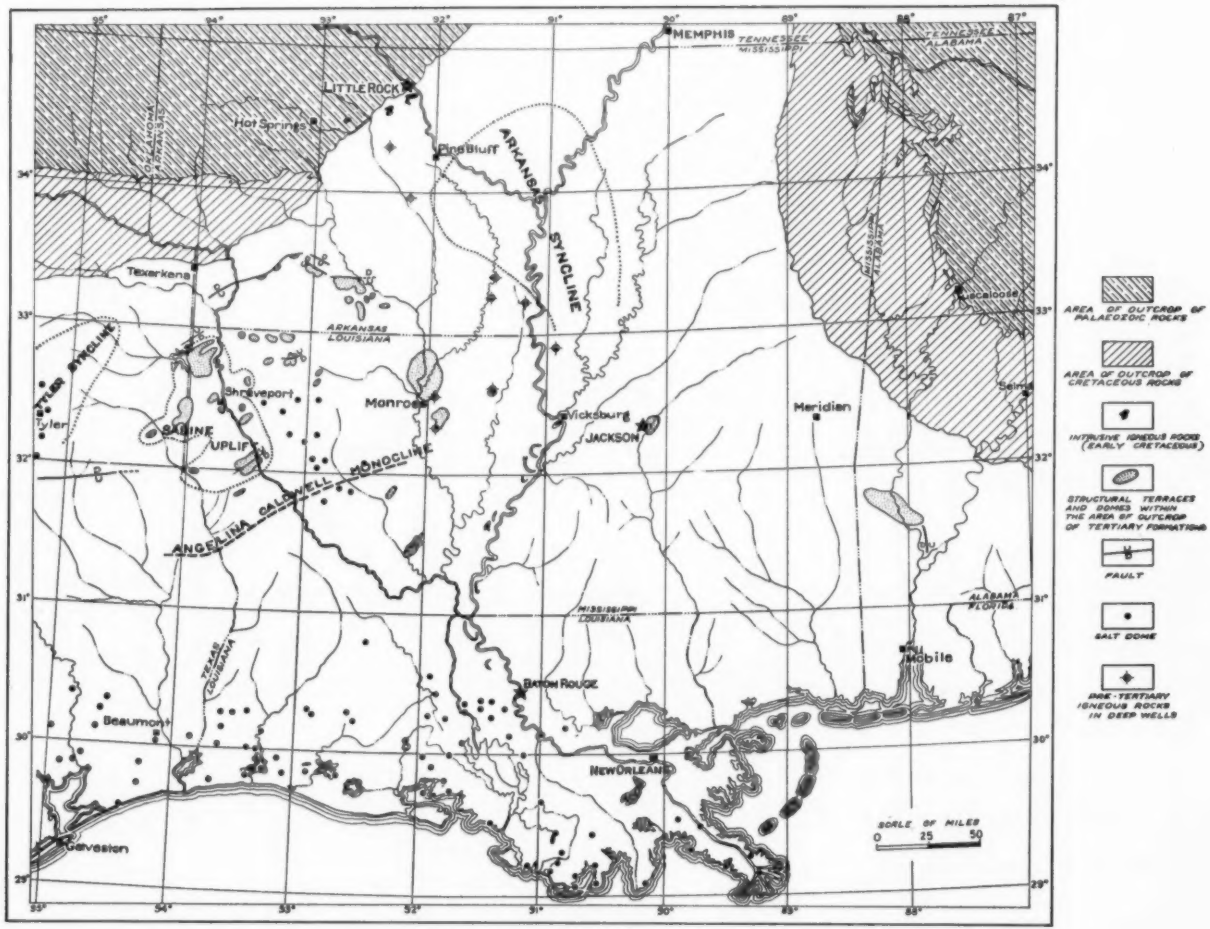


FIG. 5.—Tectonic features in region of Sabine uplift.

occurred and a remarkable flood of sand and gravel known as the Citronelle formation poured in and spread completely over the truncated pre-Pliocene sediments and the latter were buried to such a depth that a large part of Quaternary time was required to permit their exhumation by the forces of degradation.

The picture presented in the accompanying areal map of the Gulf Embayment region shows the net result accomplished in the balancing of the effects of the forces of depression and deposition against those of elevation and degradation which operated continually throughout post-Mesozoic time.

SPECULATION AS TO ORIGIN

Fluctuations of the strand line, such as have occurred repeatedly in the region of the Sabine uplift, indicate crustal instability in proportion to the degree in which they are differential. It has been shown that the Alabama Coastal Plain remained relatively stationary while widespread advances and retreats of the Eocene gulf were transpiring farther west. The structural heterogeneity of the Sabine uplift region requires an explanation in which are harmonized the episodes of Eocene history with those of late Miocene time. Periodic structural unrest culminating in the differential uplift of an area of 19,000 square miles is indicated in an interpretation of the facts of stratigraphy and observed structure. Stephenson[1] has stressed the progressive westward structural complication of the Coastal Plain, which he traces from the tectonic placidity of the Atlantic shore to the structural turbulence of the Mexican highlands. He attributes the cause of the major tilting and warping of the Coastal Plain to the decrease of load in areas of denudation with the accompanying overload and consequent depression in areas of deposition. Powers[2] sees in the Sabine uplift a local positive element of the earth's crust, antedating Cretaceous time, which has experienced periodic elevations; in its final development the area was subjected to lateral compression "exerted either from the geosynclinal prism of sediments on the south or from the land mass on the north, known as the Ouachita Mountains, or both," which produced the local folding of the uplift.

It is difficult to find support for either the hypothesis of lateral compression or the doctrine of overloading in a search for the origin of the disturbances which produced the Sabine uplift. The local structural uplifts which are superimposed on the larger regional feature are dome-

[1] L. W. Stephenson, "Major Features in the Geology of the Atlantic and Gulf Coastal Plain," *Jour. Wash. Acad. Sci.*, Vol. 16, No. 17 (1926), p. 472.

[2] *Op. cit.*, p. 124.

Fig. 5.—Tectonic features in region of Sabine uplift.

like and for the most part fail to exhibit any linear arrangement; the numerous salt domes show no evidence of lateral compression, but they, like the larger upfolds, present a clean-cut record of vertical upthrust; and the many small faults of the region are normal, indicating a readjustment following a period of tension, not of compression. The merest qualitative consideration of density values reveals the inadequacy of overloading as a cause for the development of the shallow lateral synclines which limit the Sabine uplift in Arkansas and in Texas. These troughs were outlined during the deposition of the Wilcox (early Eocene) formations; rapid accumulation is indicated by the character of the sediments and is not negatived by the paleontologic data. That these largely palustrine, rapidly deposited sediments could have become sufficiently indurated to increase their density to such a point that they could depress the basins in which they were being built up transcends all probability. A much more acceptable view is that the sediments merely filled depressions which were produced by wholly independent agencies.

The conception of differential vertical upthrust accompanied by lateral subsidence incident to the emplacement of molten matter deep in the earth's crust seems to afford an acceptable explanation for the structural heterogeneity of the region of the Sabine uplift.

The Sabine disturbance is probably genetically related to the development of the ocean deep occupied by the waters of the Gulf of Mexico. The nature and history of such earth features were inspiringly discussed by Bailey Willis in his presidential address to the Geological Society of America in 1929[1] and in a subsequent paper on "Metamorphic Orogeny,"[2] where he shows that an ocean deep may be produced by the collapse of the roof of a great magmatic reservoir, termed an "asthenolith," consequent upon the lateral expulsion of molten matter which is irrupted into the adjacent continental mass. If the assumption of the existence of an asthenolith beneath the Gulf of Mexico be justifiable, we have a mechanism adequate to account for all the facts observed in connection with our study of the Sabine uplift. The extension of the orogenic theory of Bailey Willis to account for a large but very mild earth flexure, such as is the Sabine uplift, seems to have been anticipated by that author in the statement in his second paper[3] that all the deeps of the Atlantic basin have been inactive since early Mesozoic time "except that since the middle Tertiary, adjoining lands have been gently warped."

[1]Bailey Willis, "Continental Genesis," *Bull. Geol. Soc. Amer.*, Vol. 40 (1929), pp. 281-336.

[2]*Idem*, "Metamorphic Orogeny," *Bull. Geol. Soc. Amer.*, Vol. 40 (1929), pp. 557-90.

[3]*Op. cit.*

The region of the Sabine uplift underwent igneous activity at an early period in its history. Several stocks of nepheline syenite were intruded at the dawn of Cretaceous time. Some of these are now exposed in outcrop in central Arkansas; others have been determined by deep well drilling. Basic dikes and volcanic necks of the same age are not uncommon in the area of outcrop of the sharply folded Paleozoic strata of Arkansas, and have also been identified in the deep wells of Arkansas, Louisiana, and Mississippi. The marine tuffs of the Woodbine formation of northeastern Texas and western Arkansas are interpreted as the extrusive equivalents of the per-alkaline plutonics of the Little Rock region. But, with the exception of a bentonite bed in the Midway, a thin ash in the Wilcox, and local tuffs in the Catahoula group, no Tertiary igneous rocks have been identified in the embayment part of the Coastal Plain. Geophysical studies, particularly magnetic surveys, have led to the discovery of unsuspected masses of igneous rock, but everywhere the age of these bodies has proved to be pre-Tertiary. Furthermore, both magnetic and gravimetric surveys have disproved the theory that the sharper uplifts of the region, such as the Homer structure or the interior salt domes, are the result of normal local igneous intrusion. The areas of such disturbances are ordinarily without any magnetic anomaly and almost invariably exhibit a central mass defect when investigated with the torsion balance, though the known areas of buried Cretaceous igneous rocks in many places display large magnetic intensity anomalies and are everywhere the sites of gravitational maxima.

Periodic deep-seated ejection of molten material from a profound magmatic reservoir, such as may exist beneath the Gulf of Mexico, is held to be a plausible explanation for the differential fluctuations of the sea floor clearly recorded in the Tertiary history of the embayment. A source for the vertically directed forces which produced not only the local upfolds of the Sabine uplift region, including the salt domes, but also the major structure itself is found in the irruption of this deep-seated, ejected magma into that part of the earth which underlies this area of little crustal disturbance. The depth at which such a redistribution of molten magma occurred must have been so great that interpretable effects on the magnetic or gravitational fields, produced by the change in composition of the rock column, can not now be detected at the surface. Lateral movement of this magmatic matter, probably accompanying the volume changes incident to crystallization, occurred during Wilcox time to outline the Sabine uplift and was renewed at the close of the Miocene to complete the tectonic picture.

GEOLOGICAL NOTES

DEEPER DRILLING IN WYOMING AND MONTANA

In Wyoming and southern Montana most of the important oil- and gas-bearing anticlines yield production in several different horizons and it has been much easier to discover new reserves by drilling deep tests in old fields than to find new pools of value. At Salt Creek there are six important oil sands and three other horizons of less importance. At Lost Soldier, oil occurred at six places in the stratigraphic column, and at Wertz, gas occurred at four levels. At Garland or Byron, oil or gas has been found in eight horizons.

During the last 2 or 3 years deep tests have been drilled on many of the major oil or gas structures in this area and in most places where oil was produced from upper beds it was found in lower beds. New reserves of oil were developed at Salt Creek, Oregon basin, Lost Soldier, Mahoney, Hamilton, Garland (or Byron), Byron (or East Byron), Frannie, Lance Creek, Mule Creek, and Big Muddy in Wyoming, and Dry Creek in southern Montana. More gas was found also at Big Sand Draw and Wertz. The accompanying table lists the old producing sands in these fields and the newer levels found in the last 3 years.

Of these new discoveries, three were made in the sands of the Dakota-Lakota group at the base of the Cretaceous, one in the Morrison of Jurassic age, three in Sundance sands in the Jurassic, one in the Triassic Chugwater, two in the Permian Embar formation, seven in the Tensleep, which is Pennsylvanian, and two in the Madison lime of Mississippian age.

On some other major structures deep tests failed to find any commercial oil or gas in lower beds. Baxter basin, Pilot Butte, Ferris, and Poison Spider are the notable ones, but on all of these except Poison Spider there are still untested beds that may prove productive. At Poison Spider a well was drilled to basal granite or nearly to granite and found nothing below the producing Sundance sand. At Salt Creek the deep test after finding oil in the Tensleep sand continued to granite without any more oil, because the Amsden, Madison, and Deadwood formations contained only water. There is some discussion concerning

TABLE I

LIST OF WYOMING AND SOUTHERN MONTANA FIELDS IN WHICH NEW POOLS WERE FOUND BY DEEPENING

Field	*Horizons Producing in 1928*	*New Deeper Producing Horizons*	*Depth in Feet*	*Gravity of Oil (°A.P.I.)*
Wyoming				
Salt Creek	First Wall Creek sand Second Wall Creek sand Third Wall Creek sand Several shale horizons Lakota sand Morrison sand Second Sundance sand Third Sundance (Nugget) sand	Tensleep sand	3,780	28
Oregon basin	Frontier sand—little oil	Embar lime—oil	3,350	22.3
	Dakota sand—gas	Tensleep sand—oil	3,500	20.5
Lost Soldier	Several Frontier or Wall Creek sands Dakota and Lakota sands Morrison sand Sundance (Nugget) sand	Tensleep sand	3,940	35
Mahoney dome	Dakota sand—gas Sundance (Nugget) sand—gas	Tensleep sand	4,600	34.3
Hamilton dome	Embar formation—oil	Tensleep sand	2,692	21.5
Garland (Byron)	Frontier sand—oil	Chugwater sand—gas	2,505	
	Dakota sand—gas	Embar lime—gas	3,034	
	Morrison and Sundance sands—gas	Tensleep sand—gas	3,117	
		Madison lime—gas	3,493	
		Madison lime—oil	4,400	19.2
Byron (E. Byron)	Frontier sands—gas	Sundance sand—oil	4,205	32
		Tensleep sand—oil	5,337	25
Frannie	Tensleep sand—oil	Madison lime—oil	3,010	18
Big Sand Draw	Frontier sands—gas	Morrison sand—gas	4,299	
Wertz	Frontier sand—gas	Lakota sand—gas	3,700	
	Dakota sand—gas	Sundance sand—gas	4,100	
Lance Creek	Dakota-Lakota group—gas and oil	Sundance oil	3,653	40.7
Mule Creek	Lakota sand—oil	Minnelusa sand—oil	3,162	27
Big Muddy	Frontier sand—oil	Lakota sand—oil	4,356	32
Southern Montana				
Dry Creek	Claggett sand—gas Eagle sand—gas Frontier sand—gas	Dakota sand—oil	5,412	50

the limits of the lower formations at Salt Creek, but the writer places them as follows.

Formation	*Depths in Feet*
Tensleep	3,860-4,080
Amsden	4,080-4,340
Madison	4,340-4,900
Deadwood	4,900-5,100
Granite	5,100

It is generally admitted now that a large structure in Wyoming and southern Montana still has possibilities for oil and gas until everything is tested to the top of the Deadwood formation of Cambrian age, but only three good structures have been tested to that depth; also oil and gas may yet be found in the Cambrian.

JOHN G. BARTRAM

THE MIDWEST REFINING COMPANY
DENVER, COLORADO
March 16, 1931

CORRELATION BETWEEN LATER CENOZOIC DEPOSITS OF CALIFORNIA AND OF EUROPE

Theoretical analogy led early geologists to expect marked faunal breaks between the geologic periods similar to the faunal breaks found at the ends of the geologic eras (the Paleozoic and Mesozoic), though less in degree. More recently, the boundaries between many of the geologic periods have been found to be gradational, and in California and elsewhere the boundary between the Tertiary and Quaternary has been regarded as arbitrary and indefinite; and it was considered impossible to locate it accurately. However, recent revision of the California molluscan record has revealed a marked faunal break, incomparably greater than any other faunal change that has occurred since the Oligocene, perhaps since the beginning of the Tertiary. This change is due to the chilling of the ocean waters by the oncoming of the first glaciation; and, although the change was gradual in terms of years, it was geologically abrupt. It can be used as a datum plane for correlation in nonglaciated as well as in glaciated regions and justifies the separation of the Tertiary and Quaternary. The recognition of this faunal change in California as the demonstrated equivalent of the only similar faunal change in the European section provides for the first time a reliable datum plane by which the California section can be accurately corre-

lated with the European. The overlying zones in each section can be counted upward from this datum plane and can be correlated in detail, zone for zone. In California, by means of alternating cool-water and warm-water faunas and with the help of the physiographic record, the effects of the four main glacial epochs can be recognized and correlated with the European section. Also, by working backward from this datum plane, earlier zones in the Pliocene can be compared. Failure to recognize this faunal break clearly in California has been due to the traditional separation of the Pliocene from the Pleistocene by means of the great diastrophic unconformity that can now be dated as middle Pleistocene. When the lower Pleistocene was included with the Pliocene, the records were mixed and the major faunal change was overlooked.

The views here expressed will be elaborated in Part 1 of Volume 1 of the *Memoirs of the San Diego Society of Natural History*, "A Catalogue of the Pliocene and Pleistocene Mollusca of California," by Ulysses S. Grant, IV, and Hoyt Rodney Gale, which will probably be published in April or May of this year.

HOYT RODNEY GALE

LOS ANGELES, CALIFORNIA
February 9, 1931

REVIEWS AND NEW PUBLICATIONS

Die Geologie der polnischen Ölfelder (The Geology of the Oilfields of Poland). By JAN NOWAK. (Ferdinand Enke, Stuttgart, 1929.) 101 pp., 40 figs., 1 map. Price, 13 RM.

Jan Nowak, a well known specialist, with many years of field practice in the region he describes, presents a clear, condensed, and well written survey of the geology of the Carpathian oil zone of Poland in a little book of 95 pages of text, third of a series of monographs, edited by Professor Otto Stutzer, chief of the Institute of Geology of Mineral Fuels at the venerable School of Mines at Freiberg in Saxony.

The author discusses the geology of the Carpathian oil zone in general and the principal geologic characteristics of the major oil fields, but does not discuss purely local details, production, the types of crude oil, or other technical subjects. The possible genesis of the oil is only very briefly mentioned in the closing paragraph. An extensive bibliography, covering 100 books and papers, is added.

This treatise should be very welcome to any petroleum geologist who wishes to inform himself on the exceedingly complicated conditions of sedimentation, as well as of structure, which characterize the Carpathian oil zone, where oil fields occur within a great mountain system of Alpine structure, and are intimately associated with an intricate pack of piled-up thrust sheets. American geologists, who have to deal with certain parts of California or with the Rocky Mountain front of Alberta and Montana, should be especially interested in acquainting themselves with this compact and instructive summary.

The author gives first a brief review of the structure of the northern Carpathians in general, and then discusses more in detail the Flysch geosyncline and the Upper Cretaceous, Eocene, and Oligocene orogenic sediments filling this trough, with which the oil deposits are associated. He shows how the sedimentation and the facies of the formations have been predetermined by the pre-Carpathian (Variscan) structure of the region, which, together with the later Mesozoic and Tertiary strata, was afterward remodelled into the present Carpathian folds and nappes by the Alpine orogeny. The oil fields are generally located in epi-synclinal regions, which were already depressions at the time that the Flysch was deposited and, in consequence, have a special facies of dark to black bituminous sediments, considerably less clastic than such as are associated with epi-anticlinal areas which, commonly, as early as Tertiary time, formed shoals, or emerged as ridges and island chains. Almost invariably, the north Carpathian oil fields are found on the apices of minor structural uplifts within major synclinoria, to which suitable source rocks seem to have been confined. Everywhere the oil or gas is associated with salt water, which in many places is under considerable hydrostatic pressure.

Two main groups of oil fields can be recognized.

1. The first is a northern cluster within the northwestern part of a wide epi-synclinal region, the heart of which is occupied by the valley of San River. These oil fields are situated within the middle group of the Carpathian Flysch nappes, which were mainly overthrust at the end of the Oligocene, with continued decreasing movements all through the Miocene. The oil occurs in sandstones, intercalated in black shales ranging in age from Upper Cretaceous to Oligocene. The structure is extremely complicated. The oil generally occupies the apex of structural features, but has a particular predilection for the inverted flank of overturned anticlines, and notably for the squeezed-out middle limb of complex recumbent folds.

2. The second group is the oil zone of the northeastern front zone of the Carpathians from Pzremysl to Kolomyja. To this zone belong the major oil fields of Poland: Boryslaw-Tustanowice. This frontal zone is particularly complex. The front of the nappes is broken into an infinite number of thrust slices ("skiba"), pushed over the autochtonous foreland but also overriding the buried front of lower thrust masses, which have only recently been revealed by deep drilling, which proved that even far in the Miocene foothills zone the substratum is not folded into mere open folds, but contains the buried front of flatly recumbent folds of strata ranging in age from Cretaceous to Oligocene, pushed into the Miocene, not improbably sheared of slices, dragged along and rolled in the sole of the major front sheets. Many such buried masses are sources of prolific production of petroleum, for example, at Boryslaw.

Much concerning the structure of the Carpathians is still in controversy, and much intricate detail, which would be most welcome to the petroleum geologist, is still unsolved.

In the treatise under review the author does not lose himself in such controversies, but has succeeded in giving the reader a comprehensive and clear picture of what the general geologist—not the local specialist—may be interested in.

W. A. J. M. VAN WATERSCHOOT VAN DER GRACHT

SCHLOSS HAINFELD
FELDBACH IN STYRIA
March, 1931

Physiography of Western United States. By NEVIN M. FENNEMAN. (McGraw-Hill Book Company, Inc., New York, 1931.) 534 pp., 173 figs., large insert map. Price, $5.00.

This new book by Fenneman is an indispensable addition to the working library of anyone who is at all interested in the western part of the United States. Because at least 80 per cent of the more than 2,500 geologists who are members of The American Association of Petroleum Geologists are very much concerned with the western United States, a brief description of this book is desirable. The oil geologist will find much useful material in Fenneman's contribution. The book will be sought also by college men engaged in earth science, not only as a text which describes clearly the great variety of land forms in the western part

of our country, but a comprehensive and concise treatise on underlying causal features, the nature of the rocks and their structure, and the character of dominating geologic processes and their effects. For geographers and others interested in the various aspects of man's relation to environment there is now an adequate presentation of the strongly contrasting natural provinces in the western part of the continent. In addition to these groups which will be served by Fenneman's work, this description of the western United States should be brought to the attention of non-scientists who travel extensively in the west for business or recreational purposes. Scientific or technical writing is not necessarily uninteresting or unintelligible to the layman, and the fact that Fenneman's book can be strongly recommended to the non-geologist or geographer means that the subject is handled both interestingly and very clearly. The author says, however, that "a knowledge of the elements of geology and physiography on the reader's part is assumed," and also that "the central theme of this book is mainly geological." It is clear that the presentation is designed primarily for the serious student of land forms as shown by features of the western United States.

The described region includes parts of four designated major physiographic divisions: (1) Interior Plains, (2) Rocky Mountain system, (3) Intermontane plateaus, and (4) Pacific Mountain system. Each of these is further divided into provinces, the location and limits of which are shown on a large map of the United States engraved by the U. S. Geological Survey. This map, it may be noted, is the work of Professor Fenneman in coöperation with physiographic committees of the U. S. Geological Survey, and shows the physiographic provinces and sections of the entire country. The map, which also represents the work of a committee of the Association of American Geographers, of which Professor Fenneman was chairman for several years, is a revision of the Fenneman map issued in 1914. The definition and nomenclature of the divisions, provinces, and their many sections are thus as nearly official as possible. Unless there are places where good reason can be offered for deviation from the definition of physical divisions here indicated, there is obvious desirability of uniformity in reference to them by all geologists. It is desirable, therefore, that those who have occasion to refer to matters of regional physiography should have access to the map. Inasmuch as the map is a public document issued by the Geological Survey, it may be obtained separately on application to the Survey.

The chief units described are indicated in the chapter headings, and the space allotted to each is indicated by the number of pages shown by figures in parenthesis: Great Plains Province (92), Southern Rocky Mountain Province (41), Wyoming Basin (17), Middle Rocky Mountain Province (33), Northern Rocky Mountain Province (42), Columbia Plateau (49), Colorado Plateau Province (52), Basin and Range Province (70), Sierra Cascade Province (46), and Pacific Border Province (69). Thus, 133 pages are devoted to the Rocky Mountains, 171 to the intermontane plateaus, and 115 to the Pacific Mountain system. This is a crude, by no means satisfactory, measure of the treatment of a subject, but if one considers the features to be described and remembers that the book is organized primarily on a regional basis, the discussion seems exceptionally well balanced. It is very easy to over-emphasize

parts of a subject that are best known or most interesting to an author, and to slight other parts. There is little justification for criticism of Fenneman's allotment of attention.

Besides photographs intended to illustrate at least the chief characters of the physiographic sections described, there are approximately a dozen physiographic map diagrams essentially similar to Lobeck's drawings.[1] These graphic representations of the land forms in areal distribution are a very desirable supplement to the large map showing the physical divisions. As a matter of fact, these two might be combined very advantageously in a physiographic diagram of the entire United States with the physical divisions shown as an over-print in color.

It is hardly just to say that the book is inadequately illustrated, but certainly there are not too many figures. Indeed, the reviewer feels that if there is any defect it is a paucity of illustrative material, especially of good block diagrams and sketch maps. The latter (as well illustrated by Darton's report on the structure of New Mexico)[2] may be very effective though neither elaborate nor occupying very much space. Most of the figures are well chosen, but a few of the half-tones are reproduced from other half-tones, thus resulting in the objectionable "grating" effect. Several of the photographs are new, but, with the exception of the physiographic diagrams which differ inappreciably from Lobeck's diagram of the United States, there are almost no original figures. At least one of the few maps (Fig. 110, generalized geologic map of the Colorado plateau province) is so poor that it should have been omitted. Absence of a scale and omission of drainage or other geographic frame makes this map almost unintelligible even to one familiar with the country; there is no inkling of the relation between distribution of rock formations and character of land forms so remarkably portrayed in this region.

Voluminous references to the literature and many footnote annotations are a help to the reader who desires to study parts of the subject in more detail. They also indicate care and thoroughness on the part of the author. Very recent, as well as older references, are included in the citations. Typography and press work are excellent, and the book is attractively bound in green cloth. Decidedly, Professor Fenneman and the publishers are to be complimented on the publication of this work. Its readers will look forward with very much interest to the appearance of the companion volume, *Physiography of Eastern United States*, which is in preparation.

RAYMOND C. MOORE

LAWRENCE, KANSAS
March, 1931

[1] *Physiographic Diagram of the United States.* (Geographical Press, Columbia University, New York, New York.)
Block Diagrams. (John Wiley and Sons, Inc., New York, New York, 1924.)

[2] N. H. Darton, "'Red Beds' and Associated Formations in New Mexico, with an Outline of the Geology of the State," *U. S. Geol. Survey Bull. 794* (1928). 356 pp., 62 pls., 167 figs.

RECENT PUBLICATIONS

CALIFORNIA

"Northern California's Chance for Oil," by Walter Stalder. *Petroleum World*, Vol. 28, No. 3 (Los Angeles, California, March, 1931), pp. 49-51, 127, 4 illus.

"Report on the Oil Fields on or Adjacent to the Whittier Fault," by Byron B. Norris. *California Oil Fields*, Vol. 15, No. 4 (Department of Natural Resources, Division of Oil and Gas, San Francisco, California, April, May, June, 1930), pp. 5-20, 7 pls.

"Names and Definitions of the Geologic Units of California," by M. G. Wilmarth. *U. S. Geol. Survey Bull. 826* (Supt. Documents, Washington, D. C., February, 1931). 97 pp. Price, $0.20.

GENERAL

"Bibliography of North American Geology, 1919-1928," by John M. Nickles. *U. S. Geol. Survey Bull. 823* (Supt. Documents, Washington, D. C., 1931). 1,005 pp. Price, paper cover, $1.25.

"Geological Survey from the Air," by Theodore A. Link. *World Petroleum* (New York, New York, March, 1931), pp. 229-34, 8 illus.

"Practical Interpretation of Core Analysis," by L. S. Panyity. *Oil Weekly* (Houston, Texas, March 27, 1931), pp. 32, 34, 36, 41, 7 figs.

"Planetabling from the Air. An Approximate Method of Plotting from Oblique Aerial Photographs," by O. M. Miller. *Geog. Review* (New York, New York, April, 1931), pp. 201-12, 7 figs.

"Aerial Reconnaissance Mapping in Northern Rhodesia," by C. K. Cochran-Patrick. *Geog. Review* (New York, New York, April, 1931), pp. 213-20, 8 figs.

"Note on the Theoretical Basis of Isostasy," by Walter D. Lambert. *Amer. Jour. Sci.* (New Haven, Connecticut, April, 1931), pp. 345-49.

"Possibilities of Oil Mining in Appalachian Fields," by Paul D. Torrey. *International Petroleum Technology*, Vol. 8, No. 3 (Cleveland, Ohio, February, 1931), pp. 28-34, 10 illus.

"Application of Core Drilling and Core Analysis to the Recovery of Oil," by C. E. Fralich. *International Petroleum Technology*, Vol. 8, No. 5 (Cleveland, Ohio, April, 1931), pp. 157-67, 14 figs.

GEOPHYSICS

"Gravimétrie des Formations Pétrolifères," by Arnaldo Belluigi. *La Revue Pétrolifère* (Paris, March 28, 1931), pp. 405, 406, 408-11. Illus.

"Some Observations on Geophysics," by Ronald K. DeFord. *International Petroleum Technology*, Vol. 8, No. 3 (Cleveland, Ohio, February, 1931), pp. 46-52, 2 illus.

"A New Development in Electrical Prospecting," by Hans Lundberg and Theodor Zuschlag. *Amer. Inst. Min. Met. Eng. Tech. Pub. 415* (New York, 1931). 18 pp., 14 figs.

"A Theoretical Study of Apparent Resistivity in Surface Potential Methods," by J. N. Hummel. *Amer. Inst. Min. Met. Eng. Tech. Pub. 418* (New York, New York, April, 1931). 33 pp., 9 figs.

The following papers, concluding the symposium on salt domes held recently by the Institution of Petroleum Technologists, appear in *The Petroleum Times* (London, April 4, 1931), pp. 507-9. Summaries only.

"Salt Dome Studies by Geo-Electrical Methods," by Karl Sundberg. 2 figs.

"The Salt Dome Area West of Celle, Germany," by Karl Schmidt.

"Geophysical Investigations Carried Out in the Salt-Dome Areas of the Gulf Coast of Texas and Louisiana," by Karl Schmidt.

GERMANY

"Salt Domes of North Germany," by Roderic Crandall. *Petroleum World* (New York, March, 1931), pp. 243-44. Resumé of paper read before the Institution of Petroleum Technologists, London.

ILLINOIS

"The Geology of the Pinckneyville and Jamestown Areas, Perry County, Illinois," by Alfred H. Bell, Clayton Ball, and Louis McCabe. *Illinois Petroleum No. 19* (Illinois State Geological Survey, Urbana, Illinois, April 11, 1931). Price, $0.25.

NEW MEXICO

"The Hobbs Field and Other Oil and Gas Areas in Lea County," by Dean E. Winchester. *New Mexico School of Mines, State Bureau of Mines and Mineral Resources Circular 4* (Socorro, January 1, 1931). Preliminary report. 18 pp. (mimeographed), 2 maps.

OKLAHOMA

"Structural Geology of Northeastern Oklahoma," by Sidney Powers. *Jour. Geol.*, Vol. 39, No. 2 (Chicago, Illinois, February-March, 1931), pp. 117-32, 6 figs.

TEXAS

"Development and Production History on the Salt Flat and Other Fault Fields of East Central Texas," by H. B. Hill, E. V. H. Bauserman, and Charles B. Carpenter. *U. S. Bureau of Mines Report of Investigations 3059* (Washington, D. C., March, 1931). 49 pp. (mimeographed), 3 illus.

"General Geology of Eastern Texas," by LaVerne Decker. *Oil and Gas Jour.* (Tulsa, Oklahoma, March 12, 1931), pp. 32, 148-49, 2 figs., 1 table. Partial bibliography.

"Rusk-Gregg Field 60 to 90 Square Miles," by W. C. Spooner. *Oil and Gas Jour.* (Tulsa, Oklahoma, March 26, 1931), pp. 30, 31, 131, 3 figs.

The Bureau of Economic Geology, University of Texas, Austin, Texas, announces that the following maps are now available.

"Map of the Paleozoic of Ouachita Facies in Texas," by E. H. Sellards. Advance print from "Stratigraphy of Texas," now in preparation. White print on paper. Price, $0.50.

County maps in coöperation with The American Association of Petroleum Geologists. "Brown County." The maps of "Stephens County and Palo Pinto County," revised with the addition of much new data. "Wise County," completed by addition of Cretaceous geology mapped by Gayle Scott.

"Map of Northeast Texas," by F. B. Plummer and E. C. Sargent. Shows structure and extent of Woodbine formation. Scale, 1 inch = 4.4 miles. White print on paper. Price, $2.00.

UGANDA

Summary of Progress of the Geological Survey of Uganda for the Years 1919 to 1929 (Entebbe, Uganda Protectorate, Africa, 1931). 44 pp., 6 pls., 1 map.

UNITED STATES

"Tektonische Phasen in den Prä-Mississippi-Formationen der Mid-Continent-Region," by Fanny Carter Edson. *Geologische Rundschau*, Vol. 22, No. 1 (Berlin, 1931), pp. 11-19, 6 illus.

WYOMING

"Oil and Gas Fields of the State of Wyoming." *U. S. Geol. Survey* (Washington, D. C.). New edition, February, 1931. Scale, 1 inch=8 miles. Price, $0.50.

THE ASSOCIATION ROUND TABLE

MEMBERSHIP APPLICATIONS APPROVED FOR PUBLICATION

The executive committee has approved for publication the names of the following candidates for membership in the Association. This does not constitute an election, but places the names before the membership at large. If any member has information bearing on the qualifications of these nominees, he should send it promptly to J. P. D. Hull, business manager, Box 1852, Tulsa, Oklahoma. (Names of sponsors are placed beneath the name of each nominee.)

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SIXTEENTH ANNUAL MEETING
THE AMERICEN ASSOCIATION OF PETROLEUM GEOLOGISTS
GUNTER HOTEL, SAN ANTONIO, TEXAS
MARCH 19-21, 1931

Executive Committee

Sidney Powers, president; R. D. Reed, first vice-president; Marvin Lee, second vice-president; F. H. Lahee, third vice-president; J. Y. Snyder, past-president

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Papers on West Texas and New Mexico.—R. E. Rettger, chairman; John E. Adams, R. L. Cannon

Papers on Geophysics.—G. H. Westby, chairman; H. A. Aurand, O. C. Lester, D. M. Collingwood, George M. Bevier, Paul B. Whitney

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Trips.—J. M. Dawson, chairman; F. M. Getzendaner, Dilworth Hager, Baker Hoskins, W. A. Maley, J. L. Tatum, Knox Tyson

Ladies' Entertainment.—J. B. Whisenant, chairman; Mrs. H. G. Daniels, Mrs. W. W. Kelley, Mrs. L. W. MacNaughton, Mrs. L. F. McCollum, Mrs. Ed. W. Owen, Mrs. Chas. H. Row, Mrs. J. B. Whisenant

Publicity.—R. F. Schoolfield, chairman; Robert B. Campbell, J. Howard Samuell

Exhibits.—J. D. Hedley, chairman; L. A. Douglas, H. H. Henderson

Golf.—Don Danvers, chairman; I. R. Sheldon, vice-chairman; John B. Blanchard, Louis C. Roberts.

Division of Paleontology

The Society of Economic Paleontologists and Mineralogists elected the following officers: Charles E. Decker, president; W. S. Adkins, vice-president; Gayle Scott, secretary-treasurer; and Raymond C. Moore, editor.

Golf Tournament

The annual golf tournament was held at the San Antonio Country Club. There were seventy-five players, of whom twenty were members of the San Antonio Country Club. The local committee arranged three flights and provided prizes for the three low scores in each flight and for the high score. The medalist was I. R. Sheldon, but by courtesy the medalist prize, a silver pitcher, was awarded to the visiting medalist, E. B. Hopkins. There was also the annual competition for the J. Wallace Bostick trophy. Mr. Sheldon won the trophy honor among the Association members, and Lamar G. Seeligson, of San Antonio, guest medalist, won the non-member honor, the Bostick cup. The prize scores follow.

First flight.—I. R. Sheldon—84, first, medalist, name to be engraved on Bostick trophy. E. B. Hopkins—85, visiting medalist. Elfred Beck—88, second. G. S. Norville—89, third.

Second flight.—A. C. Wright—93, first. H. A. Hemphill—93, second. Philip S. Justice—93, third.

Third flight.—G. C. Gester—93, first. T. C. Cash—96, second. R. H. Cummins—103, third. E. A. Trager—138, high.

J. Wallace Bostick cup.—Lamar G. Seeligson—84, guest medalist.

Schedule of Events

TUESDAY, MARCH 17 (PRE-CONVENTION)

10:00 A. M. Executive Committee, Sidney Powers, chairman, Gunter Hotel

WEDNESDAY, MARCH 18 (PRE-CONVENTION)

8:30 A. M. Registration, Crystal Ball Room, First Mezzanine, Gunter Hotel
Exhibit Booths, First Mezzanine, Gunter Hotel
9:00 A. M. Darst Creek-Luling Field Trip No. 1
9:00 A. M. Executive Committee
9:00 A. M. Method of Election of Officers Committee, W. E. Wrather, chairman
9:00 A. M. Association Seal Committee, Raymond C. Moore, chairman
10:00 A. M. General Business Committee, E. DeGolyer, chairman
8:00 P. M. Research Committee, Alex. W. McCoy, chairman

THURSDAY, MARCH 19 (CONVENTION)

7:30 A. M. Registration, Crystal Ball Room, First Mezzanine, Gunter Hotel
8:00 A. M. Ladies' special registration for entertainment events, Second Mezzanine, Gunter Hotel
10:00 A. M. Address of welcome, Mayor C. M. Chambers, Municipal Auditorium
Response, R. D. Reed
10:15 A. M. Technical session, Municipal Auditorium
12:30 P. M. College and fraternity luncheons
1:15 P. M. Ladies' sight-seeing trip
2:00 P. M. Technical session, Municipal Auditorium
4:00 P. M. Ladies' tea, historic old Menger Hotel

4:45 P. M. Announcement about Sixteenth International Geological Congress, W. C. Mendenhall
Annotated Bibliography of Economic Geology, Sidney Powers
Nomination of officers, Municipal Auditorium
Appointment of Resolutions and Ballot committees
6:00 P. M. United States Geological Survey dinner
8:30 P. M. Lecture with moving pictures, Laurence M. Gould, Byrd Antarctic Expedition, Municipal Auditorium

FRIDAY, MARCH 20 (CONVENTION)

8:15 A. M. Chi Upsilon breakfast, Menger Hotel
9:00 A. M. Technical session, Crystal Ball Room, First Mezzanine, Gunter Hotel
9:30 A. M. Alternate sight-seeing trip for ladies unable to attend Thursday afternoon
10:30 A. M. Society of Economic Paleontologists and Mineralogists, business meeting, Pan-American Room, Second Mezzanine, Gunter Hotel
12:15 P. M. Paleontologists' luncheon, Plaza Hotel
12:30 P. M. Sigma Gamma Epsilon luncheon
1:00 P. M. Annual Golf tournament, San Antonio Country Club
1:30 P. M. Ladies' luncheon, original Mexican restaurant
1:30 P. M. Society of Economic Paleontologists, technical session, Pan-American Room
2:00 P. M. Technical session, Crystal Ball Room, First Mezzanine, Gunter Hotel
8:00 P. M. Entertainment, Municipal Auditorium
10:00 P. M. Annual ball, Gunter Hotel

SATURDAY, MARCH 21 (CONVENTION)

9:00 A. M. Sixteenth annual business meeting, Ball Room, First Mezzanine, Gunter Hotel. Announcement of annual elections
10:00 A. M. Executive committees, joint meeting, 1931 and 1932 officers
10:00 A. M. Technical session, Crystal Ball Room, First Mezzanine
10:00 A. M. Society of Petroleum Geophysicists, business meeting, election of officers, and technical session, Pan-American Room, Second Mezzanine, Gunter Hotel
10:30 A. M. Ladies' breakfast, Plaza Hotel
12:30 P. M. College and fraternity luncheons
1:30 P. M. Laredo-Corpus Christi field trip No. 2 and Monterrey trip No. 2-A
2:00 P. M. Technical session, Crystal Ball Room, First Mezzanine
2:00 P. M. Society of Petroleum Geophysicists, technical session, Pan-American Room, Second Mezzanine
4:00 P. M. Marathon field trip No. 4

SUNDAY, MARCH 22 (POST-CONVENTION)

9:00 A. M. Edwards Plateau trip
9:00 A. M. Leave Hamilton Hotel, Laredo, for Corpus Christi trip No. 2, and Monterrey trip No. 2-A

MONDAY, MARCH 23 (POST-CONVENTION)

12:00 M. Leave Monterrey, trip No. 2-A, for San Antonio

TECHNICAL PROGRAM*

*Papers marked with an asterisk are for Vol. III of *Structure of Typical American Oil Fields*. Papers marked with a dagger were read by title only.

GROUP I. GULF COASTAL PLAIN

1.† Factors Governing Accumulation of Oil and Gas in Mirando and Pettus Districts, Gulf Coastal Texas, and Application of These Factors to Other Areas—O. L. BRACE
2. General Geology of Northeastern Mexico—JAMES L. TATUM

3. Darst Creek Oil Field, Guadalupe County, Texas—H. D. McCallum
4. Further Data on Cap-Rock Petrography—L. S. Brown
5. Overhanging Cap Rock and Salt at Barbers Hill, Chambers County, Texas—Sidney A. Judson and P. C. Murphy
6.* Structural Development of Local Geologic Features Associated with Commercial Deposits of Petroleum on Salt Domes—Marcus A. Hanna
7. Mechanics of Formation of Salt Domes—D. C. Barton
8.† Airplane Mapping—R. C. Whitehead
9. Disseminated Oil in Pleistocene Water Sands of Corpus Christi District, Texas—W. Armstrong Price
10. Kingsville Field, Kleburg County, Texas—Olin G. Bell
11. Exceptional Association of Oil and Water in Producing Zones at Refugio, Texas—R. G. Maxwell
12. Early Paleozoic Seas in Texas Region—E. H. Sellards
13.† Chapman Field of Williamson County, Texas—E. H. Sellards
14.† Chemical Character of Underground Waters of Eocene Formations of South Texas—John T. Lonsdale
15. Richland Gas Field, Richland Parish, Louisiana—Dugald Gordon
16.† Stratigraphy and Paleontology of Lower Claiborne Along Brazos River, Texas—B. Coleman Renick and H. B. Stenzel
17. Asymmetrical Folds with Special Reference to German Salt Bodies—Hans Stille

GROUP II. WEST TEXAS AND EASTERN NEW MEXICO

1. Pre-Carboniferous Stratigraphy of Marathon Uplift—Philip B. King
2. Possible Ice-Transported Deposits of Early Pennsylvanian in Upper Haymond Formation of Marathon Area, Texas—Charles Laurence Baker
3. Reef Barriers and Saline Residues in Permian of Texas and New Mexico—E. Russell Lloyd
4.* Structural Features in Limestone Reservoirs—W. V. Howard
5. Cross Sections of Permian Basin of Texas and New Mexico—H. P. Bybee, H. A. Hemphill, E. F. Boehms, C. P. Butcher, and G. E. Green
6. Geology of Hobbs Field, Lea County, New Mexico—Ronald DeFord and Edwin A. Wahlstrom
7.† Chalk Field, Howard and Glasscock Counties, Texas—W. Ralston
8.*†Structural Development of South Permian Basin Area of West Texas, with Particular Regard to Its Effect on Stratigraphy—R. L. Cannon and Joe Cannon
9. Origin and Age of Crevicing of Permian Limestone in Roswell Artesian Basin, New Mexico—S. Spencer Nye
10. Geology of Texas Panhandle—H. E. Crum and William E. Hubbard
11. Remarks on Geology of Sacramento Mountains of Southern New Mexico—J. W. Beede

GROUP III. ORIGIN, MIGRATION, AND ACCUMULATION

1.* Historical Development of Structural Theory of Oil and Gas Accumulation—J. V. Howell
8.*†Relations of Sedimentation to Origin and Accumulation of Oil—W. C. Spooner
3.* Origin and Accumulation of Oil—Frank R. Clark
4. Oil Shale Source of Crude Oil at Venice, Los Angeles County, California—H. W. Hoots and A. L. Blount
5.* Review of Current Ideas as to Source Beds for Petroleum—L. C. Snider
6.* Relation of Micro-Organisms to Generation of Petroleum—Harald E. Hammar
7.* Deposition of Organic Matter in Marine Sediments—Parker D. Trask
8.† Bacterial Genesis of Hydrocarbons—Lewis A. Thayer
9. Chemical Evidence and the Theories of Petroleum Origin—Benjamin T. Brooks
10.*†Relations of Geosynclinal Basins to Development of Petroleum Provinces—R. C. Moore
11.*†Importance of Compaction and Its Effect on Petroleum Accumulation—L. F. Athy

12.*†Study of Evidences of Lateral and Vertical Migration of Oil—F. H. LAHEE
13.*†Notes on Migration of Petroleum—CHESTER W. WASHBURNE
14.*†Oil and Gas Accumulation in Limestone—W. V. HOWARD
15.*†Structural Occurrence of Gas—HENRY A. LEY
16.*†Present Interpretations of Structural Theory for Oil and Gas Migration and Accumulation—W. ROSS KEYTE and ALEX. W. MCCOY
17.*†Importance of Unconformities on Accumulation of Oil in San Joaquin Valley, California—GEORGE M. CUNNINGIAM and W. D. KLEINPELL
18.*†Significance of Unconformities on Oil- and Gas-Bearing Structures in Gulf Coast —DAVID P. CARLTON and J. A. WATERS
19.* Problems of Origin, Gravity, Migration, and Accumulation of Oil, with Special Reference to Data Presented in *Structure of Typical American Oil Fields*—JOHN L. RICH
20.*†Physical and Chemical Factors in Accumulation and Discharge of Oil—P. G. NUTTING
21.*†Relation of Porosity to Production of Oil and Gas and Geologic Structure —A. F. MELCHER
22.*†Geologic Alteration of Petroleum—CHESTER W. WASHBURNE

GROUP IV. MISCELLANEOUS TECHNICAL

1.*†Present Status of Carbon-Ratio Theory—W. T. THOM, JR.
2.*†Temperature Gradients—C. E. VAN ORSTRAND
3.† Geothermal Variations in Coalinga Area, Fresno County, California—A. J. CARLSON
4.† Present Status of Microscopic Work in Petroleum Industry—R. D. REED
5.*†Oil-Field Waters of Appalachian Region—PAUL D. TORREY
6.*†Oil-Field Waters in Gulf Coast—H. E. MINOR
7.*†Oil-Field Waters in Mid-Continent District—L. C. CASE
8.*†Oil-Field Waters of Rocky Mountain Province—R. C. COFFIN, JOHN G. BARTRAM, and W. A. WALDSCHMIDT
9.*†Oil-Field Waters in California—N. L. TALIAFERRO
10.*†Importance of Bio-Chemical Study of Oil-Field Waters—ROY L. GINTER
11.† Venezuelan Oil-Field Waters—JAMES E. SMITH
12. Seepages in Belt Series of Rocky Mountains Near International Boundary, Canada—T. A. LINK
13.† Occurrence of Oil in Crystalline Rocks in Colorado—F. M. VAN TUYL
14.† Oil in Granite in California—W. S. W. KEW
15. Oil Production from Granite in Gray County, Texas—C. MAX BAUER
16.† Bituminous Matter in Nonesuch Formation of Northern Michigan—CHARLES G. CARLSON
17.† Miscellaneous Notes on Oil in Igneous Rocks—F. H. LAHEE
18.† Some Personal Observations of Oil in Igneous Rocks—FREDERICK G. CLAPP
19.* Characters of Oil and Origin of Differences in Various Environments—PAUL WEAVER
20.*†Variations of Gravity of Oil in Pools of the Mid-Continent Region—CHARLES H. PISHNY
21.* Variations of Gravity of Oil in Eastern Fields—K. C. HEALD
22.*†Physical Characteristics of Bradford and Other Typical Oil Sands of Pennsylvania and Their Relation to Production of Oil—CHARLES R. FETTKE
23.*†Variations of Gravity of Oil in California—PAUL W. PRUTZMAN
24.*†Variations of Gravity of Oil in Pools of Rocky Mountain District—JOHN G. BARTRAM
25.* Variations of Baumé Gravity of Oil with Depth in Gulf Coast—DONALD C. BARTON
26.† Compaction of Sediments at Cason Manganese Mine, Batesville, Arkansas—HUGH D. MISER
27. Solution to Problem of Damage Sustained Through Offset Drainage—C. A. WARNER
28. Oil Beneath Water Sands in Kansas—HOWARD S. BRYANT
29. Comparative Study of Predictive Value of Various Extrapolation Methods for Oil-Well Decline Curves—ROSWELL H. JOHNSON and BEN BLOOM

GROUP V. AREAS OUTSIDE GULF COASTAL PLAIN, WEST TEXAS, AND EASTERN NEW MEXICO

1.† Ancient Rockies and Paleozoic Correlation in Rocky Mountain Region—I. A. KEYTE and Ross L. HEATON
2. Kettleman Hills Field, Fresno and Kings Counties, California—G. C. GESTER and JOHN GALLOWAY
3.† Mississippian Formations of Eastern Interior Basin—J. MARVIN WELLER
4. Depositional and Structural Features of Michigan Synclinal Basin—R. B. NEWCOMBE
5.† Mount Pleasant Pool, Leaton Pool, and Vernon Township Pool, Michigan—GEORGE PIRTLE and W. A. THOMAS
6.† Deep Sand Development in Tioga County, Pennsylvania—JACK GADDESS
7.*†Interpretation of Local Structural Development in Areas Associated with Deposits of Petroleum in Appalachian District—W. ARMSTRONG PRICE
8.*†Interpretation of Local Structural Development in Areas Associated with Deposits of Petroleum in Mid-Continent Region—ALEX. W. MCCOY
9. Geology of Southwestern Iowa—L. D. BURLING
10. Oil Possibilities in Turkey—DJEVAD EYOUB
11. Cretaceous Limestone as Petroleum Source Rock in Northeastern Venezuela—HOLLIS D. HEDBERG
12.† Voshell Pool, McPherson County, Kansas—T. C. HIESTAND
13. Revision of Upper Permian of Western Oklahoma—HENRY SCHWEER
14. Moisture in Coal as Indicator of Oil and Gas in Pennsylvania—HARLEY S. GIBBS
15. New Points in Cenozoic History of the High Plains—F. M. VAN TUYL

GEOPHYSICS

1. Torsion-Balance Survey of Belle Isle Salt Dome, St. Mary Parish, Louisiana—D. C. BARTON
2. Refraction and Reflection Shooting—EUGENE MCDERMOTT
3. Magnetic Disturbance Caused by Buried Casing—WILLIAM M. BARRET
4. Results of Magnetometer Surveys in California—E. D. LYNTON
5. Horizontal Magnetic Intensity Attachment for Brunton Compass—JOHN H. WILSON
6. Preliminary Note on Magnetic Model Experiment—C. A. HEILAND and DART WANTLAND
7. Electrical Method for Exploring Faults and Faulted Structures—HART BROWN
8. Utilization of Existing Wells in Seismograph Work—BURTON MCCOLLUM and WILTON W. LARUE
9.† Fundamental Aspect of Eötvös Torsion Balance—R. K. JACOBSON
10.† Laboratory Experiments for Interpretation of Magnetometer Surveys—PAUL B. WHITNEY
11. Analysis of Torsion-Balance Results in California—ROBERT H. MILLER
12. New Departure in Electro-Magnetic Prospecting—HART BROWN and BEN S. MELTON

PALEONTOLOGY

1. Zonations of Upper Cretaceous on Basis of Ammonites—W. S. ADKINS
2. Post-Eocene Section of Chico Martinez Creek—PAUL P. GOUDKOFF and DONALD D. HUGHES
3. Larger *Foraminifera* of Claiborne of Texas and Louisiana—D. W. GRAVELL
4. Larger Tertiary *Foraminifera* of Venezuela—D. W. GRAVELL
5. Miocene *Foraminifera* from Los Sauces Creek, Ventura County, California—JOSEPH A. CUSHMAN and BORIS LAIMING
6. A New Species of Lower Cretaceous Ophiuroid—C. I. ALEXANDER
7. Significant *Foraminifera* of Taylor and Navarro of North-Central Texas—JOHN PETER SMITH
8. Petrographic Characters of Some Eocene Sands from Southwest Texas—M. S. METZ, M. T. HALBOUTY, and JOHN T. LONSDALE
9. Jackson Formation of Texas—ALVA C. ELLISOR
10. Marine Wilcox—JULIA GARDNER

11. Taylor Age of San Miguel Formation of Maverick County, Texas—L. W. STEPHENSON
12. Conodonts for Correlation Purposes—FRANK H. GUNNELL
13. New Ammonoids of Prolecanitidae and Cyclobiddae from Texas and Their Bearing on Correlation of Pennsylvanian Formations—F. B. PLUMMER and GAYLE SCOTT
14. Microscopic Fauna from Possible Oligocene Horizon on West Side of San Jacinto Valley, California—FRITZ E. VON ESTORFF
15. Dorothia, New Genus of *Foraminifera*—HELEN JEANNE PLUMMER
16.† Correlation Between Later Cenozoic Deposits of California and of Europe—HOYT RODNEY GALE
17. Conodonts from Basal Mississippian of Missouri—E. B. BRANSON and M. P. MEHL
18. Spores from Upper Devonian and Lower Mississippian of Missouri—R. E. PECK
19. Ostracods of Snyder Creek, Devonian, of Missouri—JOHN HARKEY
20. Conodonts from Grassy Creek Shale of Missouri—PAUL KRAUS
21. Ostracods of Sylamore Formation of Missouri—PHILIP S. MOREY

REGISTRATION

Total registration at the meeting was 1,213: 3 honorary members; 518 members, 118 associates; and 574 non-members.

REPORT OF PRESIDENT

Membership.—The American Association of Petroleum Geologists, organized by a group of about 50 field geologists in Tulsa, February 10, 1917, has grown in 14 years to a membership of 2,562 and has changed from a scientific and technical association of local interest to one of international vision and recognition. It is now the largest and, we hope, the finest geological society in the world. I wish to recommend that we add dignity to our Association by referring to it, not by initials, but as *The* Association.

The increase in broadening of scope and in membership has been at a regular rate. Several years ago we invited petroleum technologists to become members and this year, by a broadening of our constitution, we invited to membership paleontologists, geophysicists, geochemists, and all others engaged in research pertaining to petroleum geology or technology.

We continue to expand with the petroleum industry and we will render a greater service to our science and to our profession as long as we continue to improve our financial condition.

During the past year we endeavored to inquire carefully into the qualifications of all applicants for membership and for promotion from one grade of membership to the next and have verified their scholastic records and experience by means of inquiries sent to their universities, sponsors, and references. We have also changed the form used in applying for membership in order to stress the importance of professional ethics.

Monthly Bulletin.—Our Association exists for the service rendered to the members. The foremost service is in the form of publications for the mutual exchange of information and ideas. Each month we print 4,100 copies of our *Bulletin* and our mailing list is 2,800. Our *Bulletin* grows better each year. The typography and quality of our papers improves. We receive commendation from the most eminent scientists in this country.

Revolving publication fund.—One of our outstanding achievements is the establishment and increase of our revolving publication fund. The local com-

mittee for the midyear meeting held in New York City in November, 1926, gave $4,114.84 to establish this fund, the principal and interest of which can be used only for special publications. In the case of publications paid for entirely by this fund the entire income from sales reverts to the fund. When part of the cost is paid out of this fund the receipts from sales revert to the fund until the total amount advanced is reimbursed.

During the past year E. DeGolyer was authorized to raise money to increase the revolving publication fund in order that our special publications may not drain the resources of our general fund. Largely by his efforts the revolving publication fund has been increased $5,790.00 (March 21, 1931). The income from sales added to the amount received in cash made a total of $11,195.92 on March 1, 1931. The larger this fund grows, the more useful our Association becomes.

Symposium publications.—Our revolving publication fund defrayed the entire cost of publishing *Theory of Continental Drift* and *Structure of Typical American Oil Fields, Vol. I.* The fund defrayed more than two-thirds of the cost of publishing *Structure of Typical American Oil Fields, Vol. II.*

Present plans call for the publication during the next year of a third volume of *Structure of Typical American Oil Fields* to present our current theories and philosophies of the origin, migration, and accumulation of petroleum as deduced from the facts published in the preceding two volumes and elsewhere in the literature. A brief symposium on *The Occurrence of Petroleum in Igneous and Metamorphic Rocks*, authorized at the last meeting, will be published in the *Bulletin*. A symposium on *The Gas Fields of the World* under the editorial supervision of Henry A. Ley is in preparation for publication early in 1932. There is also considerable demand for a revision of our salt dome volume, now out of print, to describe *The Salt Domes of the World.*

Research fund.—Our research fund has not been touched during the past year because the research committee has not approved any projects requiring financial assistance. The total amount of this fund has been increased by paoment of pledges to $1,196.32. The work of this committee has been confined to the preparation of *Structure of Typical American Oil Fields, Vol. III.*

Life membership fund.—A special fund for life membership dues was created in 1929 when two life memberships were accepted by the executive committee. The cost is $300.00 and other members are asked to become life members for the financial benefit of the Association.

Finances.—Our financial position is gratifying. We have built up a permanent reserve for our general fund in the form of bonds, the interest derived from which is used for current expenses. Owing to the increase in service rendered our membership, the rate of increase of profits in the general fund from current business has declined during the past three years and little profit can be expected in future unless our membership continues to increase.

Our securities are now in the custody service of the Irving Trust Company, of New York City. They advise the executive committee about purchases and sales. The executive committee has passed a resolution to confine purchases to bonds within the highest two grades as classified by the Irving Trust Company, and recommends that this action become a permanent policy of the Association.

Scientific meetings.—Our Association has been honored by an invitation from the Geological Society of America to join with them in their 44th annual meeting to be held in Tulsa, December 29-31, 1931. We have accepted this invitation and have appointed Frank R. Clark, of Tulsa, general chairman of arrangements for this joint meeting.

The 16th International Geological Congress is to be convened in Washington, June, 1933. The organization committee of the Congress has awarded a vice-presidency to our Association to be filled during the next two years and a half by each succeeding president during his term of office.

Employment service.—Service to our membership has been extended to find positions for our unemployed and more suitable positions for others. Our success, although meager, has justified the expenditure of time and money for this service. Attention is called to the fact that there are openings and occasional requests to the Association for well trained men in foreign work, in teaching, and in commercial work not related to petroleum. Readjustments within the petroleum industry are taking place at an accelerated rate and the demand in future exploratory work will be for fewer, but better trained men and women, for specialists, and for those with a thorough knowledge of physics and mechanics in addition to geology. Our members must recognize that this readjustment is a permanent, not a temporary, condition, and that the petroleum industry now is becoming stabilized as the mining industry became stabilized twenty years ago when they exhausted their shallow high-grade ores, just as we have exhausted our shallow oil fields which could be operated at low cost.

Organization.—I desire to call the attention of our members to the fact that the officers, the business manager, and employees of the Association all work faithfully and conscientiously for one common cause—the interests of the Association. The correspondence and printed matter mailed from headquarters, exclusive of regular issues of the *Bulletin*, amount to 20,000 pieces a year. The correspondence of the president and third vice-president this year has amounted to approximately 2,000 letters each. Members of the executive committee have spoken on Association matters before eleven regional sections or local geological societies this year.

In conclusion, I wish to express, in behalf of those in whom you have entrusted your affairs this year, our appreciation of the cordial response our efforts have received from the entire membership.

SIDNEY POWERS, *president*

REPORT OF SECOND VICE-PRESIDENT

MEMBERS

Growth.—The complete membership list, as of March 1, 1931, is printed in the March *Bulletin*.

It is most encouraging, especially in the midst of our greatest depression in the petroleum industry, to receive so many new applications. We especially call attention to the increasing number of foreign members.

As previously reported in the *Bulletin*, we record the demise of six of our members since the last annual meeting, as follows.

G. Whitney Adams	Thos. M. Gardiner, Jr.	Henry J. Packard
C. A. Fisher	Daniel F. Higgins	George Steiner

The following statistics show some interesting, as well as disappointing, information.

Total Membership by Years

May 19, 1917	94	March 21, 1925	1,253
February 15, 1918	176	March 20, 1926	1,504
March 15, 1919	210	March 1, 1927	1,670
March 18, 1920	392	March 1, 1928	1,952
March 15, 1921	621	March 1, 1929	2,126
March 8, 1922	767	March 1, 1930	2,292
March 20, 1923	901	March 1, 1931	2,562
March 20, 1924	1,080		

Comparative Data	*March 1, 1930*		*March 1, 1931*	
Number of honorary members	7		7	
Number of members	1,683		1,848	
Number of associates	602		707	
Total members and associates		2,292		2,562
Increase in membership		166		270
Applicants elected, dues unpaid	35		43	
Applications approved for publication	89		21	
Recent applications	85		30	
Total applications on hand		209		94
Applications for transfer approved, dues unpaid	9		51	
Applications for transfer approved for publication	13		3	
Recent applications for transfer	12		11	
Total applications for transfer on hand		34		65
Number of members and associates withdrawn	18		40	
Number of members and associates dropped	46		1	
Number of members died	8		6	
Total loss in membership		72		47
Number of members and associates in arrears, previous year	78		113	
Members in arrears, current year	600		758	
Associates in arrears, current year	243		331	
Total number members and associates in arrears, current year		943		1,089

Circulation of Bulletin	*March 1, 1930*		*March 1, 1931*	
1. Subscriptions (non-members)				
Libraries	142		153	
Companies	80		72	
Individuals	52		53	
Total non-member subscribers		274		278
2. Exchanges, etc.		79		78
3. Association members and associates		2,292		2,562
Total monthly circulation of *Bulletin*		2,645		2,918

Geographic distribution of members.—Members of the Association are situated in 41 states and 34 foreign countries. Approximately 89 per cent of the membership is here within the United States. Texas continues to lead with 726 members, or 28 per cent; Oklahoma is second with 556 members or 21 per cent; California is third with 329 members, or 12 per cent; and Kansas is fourth with 108 members, or 4 per cent. These four states have 1,719 members, or 67 per cent of the entire membership.

UNITED STATES

Alabama	3	Kentucky	12	Ohio	16
Arizona	2	Louisiana	62	Oklahoma	556
Arkansas	13	Maryland	7	Oregon	3
California	329	Massachusetts	6	Pennsylvania	54
Colorado	63	Michigan	10	South Dakota	1
Connecticut	7	Minnesota	5	Tennessee	2
Delaware	1	Mississippi	15	Texas	726
District of Columbia	23	Missouri	29	Utah	3
Florida	2	Montana	8	Virginia	5
Idaho	1	Nebraska	8	Washington	1
Illinois	29	Nevada	1	West Virginia	18
Indiana	1	New Jersey	9	Wisconsin	4
Iowa	6	New Mexico	26	Wyoming	13
Kansas	108	New York	86		
Total, United States					2,283

FOREIGN

Angola, Africa	4	Ecuador	1	Philippine Islands	1
Argentina	8	Egypt	1	Poland	1
Australia	5	England	16	Roumania	6
Austria	2	France	6	Russia	5
Brazil	1	Germany	9	Scotland	1
B. West Indies	5	Holland	13	Sweden	1
Canada	37	India	1	Switzerland	12
Chile	1	Japan	5	Venezuela	56
China	1	Mexico	42		
Colombia	10	Morocco	1	Total, Foreign	279
Cuba	4	New Zealand	2	Address unknown	1
Czechoslovakia	1	Persia	3		
Dutch East Indies	13	Peru	5	Grand Total	2,562

FINANCE

Annual audit.—The complete audit of books and property for the fiscal year 1930 is published in the March *Bulletin*. Two errors were discovered after the audit was printed. Convention Receipts for 1930 were $1,550.00 instead of $2,000.00 and in the Inventory of Printed Matter the cost of the Index was $906.00 instead of $3,569.64. The Net Income for the year 1930 from the General Fund becomes a loss of $2,340.48 and the amount of the Total Liabilities and Surplus for this fund becomes $55,141.07.

Income, General Fund.—Three items of income for 1930 show a decrease. No one became a life member in 1930. The sale of the Index of Volumes I-X, inclusive, declines each year. The Salt Dome Volume was exhausted in 1929. Convention Receipts and Expenditures almost balance. More *Bulletins*, both bound and unbound, are sold annually.

Expense, General Fund.—Service and publication costs increase as the Association grows. The cost of Printed Matter Sold increases directly with the profits derived from sales.

The increase in Clerical Salaries reflects the necessity of increasing the number of office assistants in 1930. One employee was engaged during a large part of the year in examining records of applicants for membership and qualifications of associates who were possibly eligible for transfer to membership. No such transfers are made without as thorough investigation as in the case of new applicants for membership. Signatures are required from three members to sponsor admissions or transfers. Changes in the constitution and by-laws made at the New Orleans meeting required a large amount of time. Our employment service requires considerable correspondence. The executive committee has considered the cost of this additional service justified.

Publication costs have increased very little, as shown by comparative figures for the *Bulletin*.

ENTIRE EDITORIAL AND PUBLICATION COST OF BULLETIN

Year		
1929	3,900 copies monthly	$29,132.91
1930	4,000 copies monthly	30,285.98
Increase, 1,200 individual numbers		1,153.07

	Number of Pages		
	Text	*Total*	*Cost per Page*
1929	1,612	1,968	$14.75
1930	1,610	1,984	15.26

	Number of Volumes bound in Cloth
1929	907
1930	905

Cost of *Bulletins*, Indices, and Salt Dome Volumes sold, as shown by changes of inventories, excluding Cost of Publication of the *Bulletin:*

1929	Increase in inventory	$3,110.62
1930	Decrease in inventory	1,709.92

Total value of inventory of *Bulletins* and Indices on hand January 1, 1931, $13,002.05.

At the beginning of 1930, $2,579.72 was transferred from the General Fund to the Revolving Publication Fund as an allocation to pay the amount due for publishing *Structure of Typical American Oil Fields*, Vol. II, after the Revolving Publication Fund had become temporarily exhausted. Refund will be made to the General Fund after the allocation from the Revolving Publication Fund for this volume has been reimbursed to that fund.

Association funds.—There are four distinct funds: General, Revolving Publication, Research, Life Membership. The last two are inactive.

The General Fund is derived from membership dues, subscriptions to the *Bulletin*, sale of back numbers, bound volumes, indices, and the publications not printed from special funds. From the General Fund are paid all publication

expenses of the *Bulletin*, general office and administrative expense, and contributions.

The source and use of the Association's dollar are shown in the following tables.

Source	*1929*	*1930*
Dues, Members	.48	.48
Dues, Associates	.14	.12
Life Memberships	.01	.00
Subscriptions to *Bulletin*	.09	.08
Sale of Publications	.10	.11
Advertising and Miscellaneous	.14	.14
Interest on Investments	.04	.04
Convention Receipts	.00	.03
	$1.00	$1.00

Use	*1929*	*1930*
Cost of Publication of *Bulletin*	.62	.57
Salaries (Business Manager and Assistants)	.25	.26
Office and Administrative Expense	.09	.11
Contributions to Technical Division and to Publications	.02	.02
Convention Expense	.02	.04
	$1.00	$1.00

The following special publications have been financed by the General Fund. Figures apply to January 1, 1931.

Date Published	*Title Book*	*No. Pages*	*Copies Printed*	*Copies Dist.*	*Est. Cost*	*Sales Revenue*	*Publication Members*	*Price Others*
1926 (March)	*Geology Salt Dome Oil Fields*	787	1,100	1,100	$2,134.00	$5,334.82	$6.00*	$6.00
1927 (May)	*Index of Vols. I-X, incl.*	88	2,500	682	1,550.12	1,358.54	2.00	2.00
				Totals,	$ 3,684.12	$6,693.36		

*Price, $5.00 until 1927.

The Revolving Publication Fund was established by the local committee for the mid-year meeting held in New York City in November, 1926. They gave $4,114.84, the principal and interest of the fund to be used only for special publications. A permanent trusteeship of three members has now been established to have jurisdiction with succeeding executive committees over the disbursement of this fund. The fund has been increased this year, largely through the efforts of E. DeGolyer, by more than $5,000 cash and the present total fund (March 1) is $11,195.92.

The following tabulation shows the disposition of the fund in the past, statement as of January 1, 1931.

Date Published	*Title Book*	*No. Pages*	*Copies Printed*	*Copies Dist.*	*Est. Cost*	*Sales Revenue*	*Publication Members*	*Price Others*
1928 (March)	*Continental Drift*	240	1,500	1,328	$2,981.46	$3,689.49	$3.50	$3.50
1929 (March)	*Structure Typical American Oil Fields, I*	510	2,500	1,913	$7,279.11	$7,447.80	4.00	5.00
1929	*Structure Typical American Oil Fields, II*	780	2,500	1,479	9,813.00*	6,406.59	4.00	6.00
				Totals,	$20,073.57	$17,543.99		

*Allocation from General Fund, $2,579.72.

The Research Fund on March 1 was $1,196.32. This fund is to be disbursed by a permanent trusteeship of three members in conjunction with the executive committee.

The Life Membership Fund amounts to $600.00. It is hoped that more members will apply to the executive committee to become life members at a cost of $300.00.

Investments.—In August, 1930, it was found that the advice upon which securities were purchased was not satisfactory to the executive committee and thereafter all bonds were selected with great care. In order to secure the best possible advice concerning investments, our securities were transferred on January 30, 1930, to the custody service of the Irving Trust Company, New York City.

The executive committee resolved to purchase in future only bonds of high rating recommended by the Irving Trust Company and classed as (I) those involving a minimum of risk or (II) those deemed sufficiently well secured under normal conditions for holders to disregard current developments. The following bonds were purchased during 1931 under these specifications.

General Fund	*Interest*	*Expiration*	*Cost*
1 Wabash Railroad Company, 2d mortgage	5	1939	$1,012.50
Revolving Publication Fund			
2 Western Union Telegraph Company	5	1951	2,075.00
1 Texas and Pacific Railway Company, 1st mortgage.....	5	2000	1,125.00
Research Fund			
1 Great Northern Railway, series E	4½	1977	987.50
Life Membership Fund			
1 Oregon Short Line, 1st mortgage ($500 bond).....	5	1946	545.00

CONCLUSION

In conclusion, it may be said that the Association performed a greater service in 1930 than in any previous year. Although the audit did not show the large financial gains of previous years, the organization has been improved, and, if dues are paid promptly, it can continue with the present program of service to our membership.

MARVIN LEE,
Second vice-president in charge of finances

REPORT OF THIRD VICE-PRESIDENT

The editorial staff of our Association is concerned, directly or indirectly, with two major activities: (1) the *Bulletin*, which is financed through the General Fund; and, (2) certain special publications which, as far as possible, are financed by the Revolving Publication Fund, and which may be the results of investigations conducted through our research committee. These two groups of publications include the greater proportion of the permanent contributions of our organization to the petroleum industry and to science.

The *Bulletin*, as you know, contains several departments. I want to say a few words concerning each of these, at the same time comparing statistics for the years 1929 and 1930.

In 1929 we printed 1,612 pages, and in 1930, 1,610 pages, exclusive of advertisements.

Of the major articles, 69 were published in 1930 as contrasted with 60 in 1929. These 69 papers required 1,108 printed pages contrasted with 1,191 for the 60 articles. In 1929, the 60 contributions were divided as follows:[1] 28 on structural geology, or topics pertaining thereto, 25 on stratigraphy, 5 on geophysics, and 2 on miscellaneous subjects. In 1930 the 69 papers included 32 on structural geology, 21 on stratigraphy, and 15 on geophysics.

Regarding the papers on geophysics, 4 out of the 5 published in 1929 were strictly physical, whereas, in 1930, only 1 was definitely physical, all the other 14 having a very close bearing on geology. All the major articles in the September number of the *Bulletin* were devoted to geophysics. In 1929 the 5 papers on geophysics occupied 112 pages. In 1930 we printed 232 pages on this branch of our science, or more than enough for two numbers of the *Bulletin*.

We have been much gratified by the interest shown by the members in the department on Geological Notes. In 1929 there were 69 pages given to 22 of these minor articles, and in 1930 we printed 33 notes on 118 pages. Let me remind you of the peculiar importance of this department in that here we are able to print short contributions on new discoveries or on subjects of current value, without the need of formal presentation and without the delay unavoidable in the publishing of major articles. The editors will always welcome short papers for Geological Notes.

[1]In making this abbreviated classification, I have relegated to each topic the papers most closely related to it. For example, a paper on compaction of sediments is included in structural geology, and a paper on petroleum source rocks is included in stratigraphy.

In our department, Discussions, 16 contributions, or 38 pages, were printed in 1929, and 17 contributions, or 42 pages, in 1930. This department opens the way for adding new facts, experiences, or conclusions, relating to papers already published in the *Bulletin;* and it gives opportunity for thoughtful and courteous expression of differences of opinion. We invite its use, but we suggest that contributors phrase their discussions in tactful language, with the object of broadening knowledge or perhaps of politely correcting actual errors.

Under Research Notes, 12 pages were printed in 1929, and 14 pages in 1930. I do not think that this department is used as widely as it might be. Let us have more suggestions from members for possible lines of research. When a member is eager to secure information from widespread sources on some particular research problem, I can see no reason why he should not avail himself of this department for printing a questionnaire to cover the data which he seeks.

In 1930 we inaugurated a new department, Suggestions to Authors. Here, from time to time, we shall print advice as to preparation of manuscripts, or answers to questions from members who desire information concerning the details of writing for publication. We shall be glad to receive suggestions.

In 1929, 35 reviews of other publications were printed, and in 1930, 26. These reviews are of real value for those who want to keep abreast of the progress in their science. We have been justly criticized, we American authors, for our almost complete scientific isolation. We forget that many of the problems on which we are working have been studied and described in print in other countries. We are too apt to overlook or neglect the contributions of foreign scientists.

For the At Home and Abroad department, members are requested to send in their own news items, and these should refer principally to changes of business connections, residence, or special activity.

Our *Bulletin*, representing a diversity of interests and motives, widely scattered not only in this country but also abroad, receives contributed articles on many subjects and on many different localities. For one man, or two, to edit these papers would be neither practical nor wise. We have, therefore, a board of associate editors, regionally distributed. It is the duty of each one of these associate editors to read and pass on the manuscripts pertaining to his territory. We have recently added to the number of these associate editors, and we believe that still more should be invited to the staff. What I want to impress on you and also on these associate editors themselves is that their responsibility is increasingly great in proportion as our Association grows, for to them we must look for the basic decision as to the merits of papers relating to their respective districts or fields of science. The editor must be able to place reliance on their opinions. He may be called upon to use his judgment in cases of doubt, but the executive duties of his office are becoming more and more strongly emphasized in contrast to his strictly editorial duties. These two trends, namely, the growing tendency toward executive functioning of the editor, and the delegation of more editorial responsibility to the associate editors, are a natural consequence of the development of our Association to the important place which it now occupies.

In concluding, permit me to stress once more the value of our special publications. We have produced four: *Theory of Continental Drift, Geology of Salt Dome Oil Fields,* and the two volumes *Structure of Typical American Oil Fields.* We have been criticized because some chapters in these volumes had previously been published in the *Bulletin.* For your information I will say that we are avoiding similar double printing of articles for Volume III of *Structure of Typical American Oil Fields.* The articles for Volume III will not appear in the *Bulletin.* This volume, as you have been advised in your local meetings, will be comprised of papers on philosophical subjects, not on local fields as in volumes I and II. The primary objects of compiling Volume III are, (1) to summarize and evaluate the data presented in volumes I and II, going beyond the limits of these two volumes if desirable; and (2) to outline and classify problems which offer an attractive field for research. All of us are well aware of the numerous deficiencies in our understanding of petroleum geology. Volume III, we hope, will help to direct our studies toward a better comprehension of this broad field of scientific learning.

We now have a substantial Revolving Publication Fund, thanks to the generosity of many members and local societies. It is enough to finance one book similar to *Geology of Salt Dome Oil Fields.* We should continue to build up this fund, for its purpose is to carry on the biggest, most important single achievement of our Association. Granting that our special publications continue to be of high quality and usefulness, I thoroughly believe that they will stand out as the most enduring monument to our progress and service.

FREDERIC H. LAHEE,
Third vice-president in charge of editorial work

REPORT OF ANNUAL ELECTIONS

All nominees for officers of the Association, proposed in open meeting, on the first day of the convention, were unanimously elected as follows: Lovic P. Garrett, of Houston, Texas, president; L. Courtney Decius, of San Francisco, California, first vice-president; Frank Rinker Clark, of Tulsa, Oklahoma, second vice-president; and F. H. Lahee, of Dallas, Texas, third vice-president (re-elected).

MINUTES, SIXTEENTH ANNUAL BUSINESS MEETING, GUNTER HOTEL, SAN ANTONIO, TEXAS, MARCH 21, 1931

SIDNEY POWERS, *presiding*

The meeting was called to order at 9:30 A. M., by president Powers. The minutes of the fifteenth annual meeting were not read, by unanimous consent. After the reading of the annual reports by the officers, the report of the business committee was read by chairman DeGolyer.

REPORT OF BUSINESS COMMITTEE

(The following recommendations in the form of motions were proposed by the committee and carried by the Association.)

1. *Publication.*—To recommend the approval of the research committee's plan for a volume on natural gas, as follows.

The research committee, on the motion of F. H. Lahee, seconded by W. E. Wrather and others, unanimously voted to endorse a project under the auspices of the Association to compile a symposium of papers on the *Geology of Natural Gas;* these papers to be edited and printed in a special publication to be financed by the Revolving Publication Fund; and to approve the appointment of Henry A. Ley as editor of this symposium.

Research committee, DONALD C. BARTON, *vice-chairman*

2. *Structure of Typical American Oil Fields, Volume III.*—To recommend the publication of Volume III, *Structure of Typical American Oil Fields,* with the aid of the Research Committee and the Revolving Publication Fund.

3. *Geological Society of America.*—To accept the invitation of the Geological Society of America to hold a joint meeting with the Association in Tulsa, December 29, 1931; and to appoint Frank R. Clark chairman of arrangements for that meeting.

4. *International Geological Congress.*—To recommend a gift of $500.00 for the years 1931 and 1932, respectively, to the organization committee of the 16th International Geological Congress, to aid in defraying preliminary expenses.

5. *Affiliated societies.*—To recommend approval of the petitions of the following societies for affiliation with the Association, under provisions of the constitution and by-laws as provided in Article IV, Section 3 of the by-laws.

Alberta Society of Petroleum Geologists, Calgary, Alberta, Canada
Charleston Geological Society, Charleston, West Virginia
Fort Worth Geological Society, Fort Worth, Texas
Houston Geological Society, Houston, Texas
Kansas Geological Society, Wichita, Kansas
Midland Geological Luncheon Club, Midland, Texas
Oklahoma City Geological Society, Oklahoma City, Oklahoma
Shawnee Geological Society, Shawnee, Oklahoma
Tulsa Geological Society, Tulsa, Oklahoma

6. *Society of Economic Paleontologists and Mineralogists.*—To recommend that the Association allot $2.00 of the 1931 dues of each of its members who is also a member of the Society of Economic Paleontologists and Mineralogists, to the activities of the Society of Economic Paleontologists and Mineralogists.

7. *Geophysical papers.*—To recommend that the geophysical papers may be assembled as a separate volume.

8. *Association seal and emblem.*—To approve the California design as redrawn and recommended by the committee for the Association seal. To accept the design of the seal also for a badge or emblem with such slight revision by the committee as is essential to make its manufacture practicable.

9. *Employment service.*—To recommend that the employment service be continued and that coöperation between the Association and the American Institute of Mining and Metallurgical Engineers be used to further the employment service of both organizations.

10. *Trusteeships.*—In conformity with the action of the executive committee at Tulsa, Oklahoma, May 23, 1930, it was decided that the executive committee instruct the president to appoint trusteeships for the research and revolving publication funds.

Each trusteeship shall consist of three members, each of whom will be appointed to serve for 3 years, but in rotation, one member being appointed each year. To accomplish this method of tenure, one of the first appointees shall serve for 1 year only; and another for 2 years only. Except for these two, all appointments shall be for 3-year terms. Selection of members of these trusteeships shall be made by the executive committee.

11. *Foreign geologists.*—That the Association should make greater efforts to form contacts with foreign geologists who are eligible to become members of the Association.

(The following recommendation of the business committee was amended as shown.)

12. *Report of committee on methods of election of officers.*—To accept the following report of the committee.

The committee on method of election of officers has thoroughly studied every submitted proposal bearing on this question and on its own account has endeavored to devise possible new methods. It has reached the conclusion that a change in the present method is not feasible. It recognizes the desirability of according to every member the opportunity of voting for officers, but in view of the wide geographic distribution of membership and of its constant change of location, the committee is of the opinion that the delay incident to balloting would necessarily be so great as to seriously impede the conduct of the business of the Association.

Amendment.—That the letter of January 15, from the committee on methods of election of officers to the district representatives, together with the summary of proposals for election of officers, which was attached to that letter, and also a summary statement of the results of the balloting on this matter in the several districts, be incorporated in the minutes of this business meeting for publication in the Association *Bulletin.*

(The letter, proposals, and results follow.)

Dallas, Texas, January 15, 1931

To District Representatives.

GENTLEMEN:

Herewith is a summary of the various proposals dealing with the election of officers which have been gathered by the committee appointed for this purpose at the New Orleans meeting. This summary sets forth in condensed form the advantages and disadvantages of the present method of election, and it includes also several new proposals.

Will you kindly bring this subject up for discussion at the earliest opportunity before your local society and endeavor to secure an expression of opinion which will enable you to vote at San Antonio (1) for or against the retention of the present method of election; (2) for or against the three proposals set forth in Section IV of the summary; or (3) to propose in concrete form any other scheme of election which may meet with the approval of your constituency.

Kindly try to secure as promptly as possible some action by your local group, and have the subject well enough in hand so that a decisive vote will be possible at San Antonio. The prolonged discussion of this topic should have sufficiently crystallized opinion by this time to enable us finally to bring it to a definite conclusion.

Very sincerely yours,

W. E. WRATHER, *chairman* ROY E. DICKERSON
H. B. FUQUA, *vice-chairman* W. B. HEROY
F. S. HUDSON J. V. HOWELL
A. F. CRIDER

SUMMARY OF PROPOSALS FOR ELECTION OF OFFICERS

I. Undesirable features of present system
   a. Members not attending annual conventions have no opportunity to vote, although constitutionally they have the right to vote
   b. Possible reduction of interest in Association affairs for members unable to vote
   c. Since ordinarily only between 20 per cent and 30 per cent of the members are able to attend our annual convention, the vote is not representative of the whole Association
   d. Occasions some unfortunate politics

II. Desirable features of present system
   a. Affords opportunity for incoming and outgoing executive committees to hold joint session, this being a very important advantage
   b. Permits prompt action in combined procedure of nomination and election
   c. Avoids the undesirable features of a nominating committee, which may acquire the nature of an oligarchy
   d. Gives opportunity to attending members to meet and judge candidates
   e. Serves as an incentive to some members to attend the annual convention
   f. Most democratic method
   g. The business representatives, presumably reflecting the consensus of opinion of a large majority of the membership, are present and have ample opportunity to make nominations if they care to do so

III. Additional ideas presented by committee
   a. To date the present method has been essentially successful
   b. A mail ballot is regarded as a distinct nuisance by many members of other societies which have adopted it

IV. Other methods proposed, with objections
   a. 1. Nominating committee of 5 most recent past-presidents
      2. 15 nominations
      3. Vote by double mail ballot before annual convention
      4. Announcement at business meeting
         This method would have disadvantages of nominating committee and mail ballot, but would permit voting by all qualified members and would permit joint meeting of incoming and outgoing executive committees during convention
   b. 1. Nominations by petition signed by at least 50 members and received by business committee not later than midnight of first day of convention. If less than two candidates for any office, business committee to supply additional nominations necessary.
      2. Voting as at present
         This plan would give absentee members a chance to select nominees and would avoid disadvantages of nominating committee and mail ballot. It would permit joint session of executive committees at convention

c. 1. Nominations from floor as at present
2. Voting by mail ballot
3. Officers to take office July 1

This method limits nominating to those present at convention, but permits all active members to vote; but it has the disadvantage of preventing joint executive session, since all members of both executive committees might never be brought together unless at the annual convention

DISTRICT DECISIONS ON METHOD OF ELECTION OF OFFICERS

Districts in favor of present method: (1) Canada, (2) Dallas, (3) Fort Worth, (4) Great Lakes, (5) Houston, (6) New York, (7) Pacific Coast, (8) San Antonio, (9) Shreveport, (10) West Oklahoma, (11) Wichita, (12) Wichita Falls

District with tie vote: Capital

Districts in favor of some other method: (1) East Oklahoma and (2) Southern Permian Basin

Districts not heard from: (1) Amarillo, (2) Appalachian, (3) Mexico, (4) Rocky Mountains, (5) South America

Business committee, E. DEGOLYER, *chairman*
MARVIN LEE, *secretary*

H. E. BALE	W. B. HEROY	SIDNEY POWERS
DONALD C. BARTON	J. V. HOWELL[3]	R. D. REED
S. P. BORDEN	R. F. IMBT	CHAS. H. ROW
FRANK R. CLARK	F. H. LAHEE	GAYLE SCOTT
L. C. DECIUS	A. I. LEVORSEN	L. C. SNIDER[5]
H. B. FUQUA	THEO. A. LINK	J. Y. SNYDER
L. P. GARRETT[1]	H. D. MISER	WILLIS STORM
G. CLARK GESTER	R. C. MOORE	J. M. VETTER
S. A. GROGAN	R. B. MORAN[4]	
ROY H. HALL[2]	F. A. MORGAN, JR.	

[1]Garrett represented Alexander Deussen
[2]Hall represented L. W. Kesler
[3]Howell represented A. W. Duston
[4]Moran represented C. R. McCollom
[5]Snider represented H. J. Wasson

REPORT OF RESOLUTIONS COMMITTEE

Be it resolved, that we express our appreciation and thanks to the following who have contributed to the success of the sixteenth annual meeting in San Antonio.

1. The City of San Antonio for its hospitality and the excellent facilities placed at the disposal of the Association.

2. The San Antonio Chamber of Commerce, represented by Nat Goldsmith and H. W. Jones, who have so largely contributed to the success of the meeting.

3. The Gunter Hotel, The Baker Corporation, and in particular, Paul McSween, the manager of the Gunter, and W. E. Corrin, assistant manager, for the excellent service rendered the Association in connection with this meeting.

4. The numerous San Antonio firms and individuals, and in particular, F. P. Zoch, and his committee, who have contributed so generously to the expense incurred in connection with this meeting.

5. The San Antonio section of The American Association of Petroleum Geologists, D. R. Semmes, president, and the various committees, who have assisted the officers of the Association in making the convention a complete success.

Whereas, two of our oldest and most loyal members, Alexander Deussen and David White, on account of serious illness, have been unable to attend the meeting;

Be it resolved, that we express our regret that they have been unable to be present and tender them our best wishes for speedy recovery.

Be it resolved, that these resolutions be spread upon the records of the Association and that a copy of each specific resolution be mailed to the individuals, societies, and organizations mentioned.

Resolutions committee, FRANK A. MORGAN, *chairman*
HUGH LEE BURCHFIEL
HERSCHEL H. COOPER

The meeting adjourned.

MARVIN LEE, *second vice-president*

EXECUTIVE COMMITTEE MEETING
SAN ANTONIO, MARCH 17-18, AND 21, 1931

The executive committee met at San Antonio, Texas, in connection with the sixteenth annual convention of the Association. On March 17 and 18, all members of the out-going committee were present: president Powers of Tulsa, past-president Snyder of Shreveport, first vice-president Reed of Los Angeles, second vice-president Lee of Wichita, and third vice-president Lahee of Dallas.

Investments.—Purchase of high-grade bonds for the following funds was authorized: revolving publication fund, $1,000; research fund, $1,000; life membership fund, $500. These amounts were transferred from temporary investment.

Employment service.—It was recommended to continue the Association employment service for members, and to coöperate with other organizations in such service.

Income.—It was agreed that advertising in the *Bulletin* is an important part of the Association's income and that efforts should be made to secure more advertising. It was suggested that members be urged to patronize *Bulletin* advertisers.

Affiliated societies.—The applications of the following geological societies were approved and actual affiliation recommended, pending formal acceptance of constitutional conditions by the societies: Alberta Society of Petroleum Geologists, Charleston, Fort Worth, Houston, and Kansas geological societies, Midland Geological Luncheon Club, and Oklahoma City, Shawnee, and Tulsa geological societies. Only persons who are fully qualified members

of the Association are permitted to use the words "Affiliated with The American Association of Petroleum Geologists" on their professional cards or otherwise.

Research fund trustees.—It was moved that the president appoint a trusteeship for the research fund as follows: W. E. Wrather for 3 years; Thomas S. Harrison for 2 years; and Alex. W. McCoy for 1 year.

Revolving publication fund trustees.—It was moved that the president appoint a trusteeship for the revolving publication fund as follows: E. DeGolyer for 3 years; Alexander Deussen for 2 years; and R. D. Reed for 1 year.

Geological Society of America.—The invitation of the Geological Society of America to hold a joint meeting with the Association in Tulsa, December 29, 1931, was accepted and Frank R. Clark was appointed chairman of arrangements.

New Mexico district.—Subject to approval by the Rocky Mountain and Southern Permian Basin districts, the states of Arizona and New Mexico were designated as a new district to be known as the New Mexico district.

On March 21, all members of the out-going and in-coming committees were present in joint meeting. The new committee comprises: president Garrett of Houston, past-president Powers of Tulsa, first vice-president Decius of San Francisco, second vice-president Clark of Tulsa, and third vice-president Lahee of Dallas.

Organization.—President Garrett was appointed chairman and second vice-president Clark was appointed secretary of the executive committee.

Investments.—It was decided to continue the action of the last executive committee in regard to investment in high-grade conservative bonds. Arrangements were made to bond the president, past-president, second vice-president, and business manager.

Geophysical papers.—It was decided that all geophysical papers published in the *Bulletin* in 1931 may be assembled in a separate volume.

ASSOCIATION COMMITTEES

EXECUTIVE COMMITTEE

LOVIC P. GARRETT, *chairman*, Gulf Production Company, Houston, Texas
FRANK RINKER CLARK, *secretary*, Mid-Kansas Oil and Gas Company, Tulsa, Oklahoma
SIDNEY POWERS, Box 2022, Tulsa, Oklahoma
L. COURTNEY DECIUS, Associated Oil Company, San Francisco, California
F. H. LAHEE, Box 2880, Dallas, Texas

GENERAL BUSINESS COMMITTEE

J. P. BOWEN (1932)
FRANK R. CLARK (1932)
R. CLARE COFFIN (1933)
VICTOR COTNER (1932)
L. COURTNEY DECIUS (1932)
H. B. FUQUA (1933)
LOVIC P. GARRETT (1933)
S. A. GROGAN (1933)
W. R. HAMILTON, (1933)
HARRY R. JOHNSON (1933)
L. W. KESLER (1933)
R. S. KNAPPEN (1933)
FREDERIC H. LAHEE (1932)
C. R. MCCOLLOM (1932)
H. D. MISER (1932)
JOSEPH E. MORERO (1933)
ED. W. OWEN (1933)
LEON J. PEPPERBERG (1933)
SIDNEY POWERS (1932)
R. D. REED (1933)
A. H. RICHARDS (1933)
S. C. STATHERS (1933)
WILLIS STORM (1932)
H. J. WASSON (1933)
THERON WASSON (1933)
JOHN F. WEINZIERL (1933)

RESEARCH COMMITTEE

ALEX. W. MCCOY (1932), *chairman*, 919 East Grand Avenue, Ponca City, Okla.
DONALD C. BARTON, (1933), *vice-chairman*, Petroleum Building, Houston, Texas
C. R. FETTKE (1932)
A. I. LEVORSEN (1932)
SIDNEY POWERS (1932)
R. D. REED (1932)
L. C. SNIDER (1932)
W. C. SPOONER (1932)
W. T. THOM, JR. (1932)
F. M. VAN TUYL (1932)
W. E. WRATHER (1932)

REPRESENTATIVES ON DIVISION OF GEOLOGY AND GEOGRAPHY NATIONAL RESEARCH COUNCIL

R. C. MOORE (1933)
ALEX. W. MCCOY (1931)

REPRESENTATIVES ON NATIONAL STRATIGRAPHIC NOMENCLATURE COMMITTEE

A. I. LEVORSEN, *chairman*, 1740 South St. Louis Avenue, Tulsa, Okla.
M. G. CHENEY
C. J. HARES

REVOLVING PUBLICATION FUND

E. DEGOLYER, *chairman*, 65 Broadway, New York, N. Y.

RESEARCH FUND

LUTHER H. WHITE, *chairman*, J. A. Hull Oil Company, Tulsa, Okla.

AT HOME AND ABROAD

CURRENT NEWS AND PERSONAL ITEMS OF THE PROFESSION

EMPLOYMENT

The Association maintains an employment service at headquarters under the supervision of the business manager.

This service is available to members and associates who desire new positions and to companies and others who desire Association members and associates as employees. All requests and information are handled confidentially and gratuitously.

To make this service of maximum value, all members and associates in the Association are requested to coöperate by notifying the business manager of openings available.

GEORGE R. ELLIOTT has been appointed petroleum engineer for the Department of the Interior, Calgary, Alberta, Canada.

ARTHUR WADE, 19 Basinghall Street, London, E. C. 2, England, has an article in the February 14 issue of *The Petroleum Times* (London), entitled "Intrusive Salt Bodies in Coastal Asir, South-Western Arabia." This is a summary of a paper read at a recent symposium on salt domes before the Institution of Petroleum Technologists.

WILLIAM GLENN BARTLE, aged 7, son of Mr. and Mrs. GLENN G. BARTLE, of Kansas City, Missouri, died on February 26, 1931, of acute pericarditis. Mr. Bartle is a member of the faculty of the Kansas City Junior College.

HAROLD J. COOK, curator of paleontology at the Colorado Museum of Natural History, Denver, has resigned from the active staff of the museum in order to devote full time to personal affairs and to the active development of the Cook Museum of Natural History at Agate, Nebraska.

Mr. Cook is the author of a brief article in the discussion department of *Science*, March 13, entitled "More Evidence of Mammoths in the High Mountains of Colorado."

TOM L. COLEMAN, district engineer, United States Geological Survey, Wichita Falls, Texas, is the author of an article, "Repressuring in Red River Oil Field," published in the March 19 issue of *The Oil and Gas Journal*.

E. P. HINDES has been appointed chief geologist for Henry L. Doherty and Company, 60 Wall Street, New York, New York.

W. T. THOM, JR., of the department of geology, Princeton University, Princeton, New Jersey, gave a talk on "Some Economic Phases of Geology" before the San Antonio Geological Society on February 2. On March 2, V. H.

McNUTT, 916 Milam Building, San Antonio, discussed the potash industry before the society, giving a very comprehensive survey of the exploration and production of potash and the relation of American deposits to the world supply.

HARRY W. OBORNE is consulting geologist for the Essco Petroleum Company, with offices at 603 Giddens-Lane Building, Shreveport, Louisiana.

E. DEGOLYER, 65 Broadway, New York, New York, has a brief paper on "Origin of the Salt Domes of the United States Gulf Coastal Plain" in the February 28 issue of *The Petroleum Times*. This is a summary of a paper read at the Institution of Petroleum Technologists' recent symposium on salt domes. LAUNCELOT OWEN, of the geological department of the Royal School of Mines, London, England, also presents in this issue a summary of his paper on "Moot Points in Salt Dome Theory."

CLAUDE F. DALLY, consulting geologist, of Fort Worth, Texas, has a paper entitled "Geologically, East Texas Is Most Interesting" in the March 6 issue of *The Oil Weekly*.

O. STUTZER, of the Saxony Mining School, Freiberg, Saxony, Germany, has a brief article entitled "Mehr Einheitlichkeit in der Bezeichnung der Ölmenge," published in the March 4 issue of *Petroleum Zeitschrift*.

HENRY ROGATZ has resigned as geologist for the Phillips Petroleum Company in the Panhandle district of Texas and has returned to Columbia University for work toward a doctor's degree in geology.

R. B. NEWCOMBE, of the Geological Survey Division, Lansing, Michigan, has an article on "Middle Devonian Unconformity in Michigan" in the December, 1930, issue of the *Bulletin of the Geological Society of America*.

ROSS L. HEATON, 2374 Elm Street, Denver, Colorado, addressed the Denver chapter of the Rocky Mountain Association of Petroleum Geologists, March 5, 1931, on the subject, "The Ancestral Rockies."

R. E. STEWART, geologist with the Chanslor-Canfield Midway Oil Company, Ventura, California, is teaching petroleum geology at the University of Southern California during the absence of A. J. TIEJE, chairman of the geology department. Dr. Tieje, who is on sabbatical leave at the University of Oklahoma, Norman, to study methods of correlation in the Mid-Continent oil fields, will again be in charge of the summer session courses in geology at Columbia University.

BRUCE L. CLARK, University of California, Berkeley, California, has a paper entitled "Tectonics of the Coast Ranges of Middle California," in the December, 1930, issue of the *Bulletin of the Geological Society of America*.

Mr. and Mrs. RONALD J. CULLEN announce the birth of a daughter, Margaret Weir Cullen, on March 12, 1931. Mr. Cullen is with the Twin State Oil Company.

CHARLES H. BEHRE, JR., department of geology, Northwestern University, Evanston, Illinois, is the author of a brief article in the discussion depart-

ment of the February 27 issue of *Science*, entitled "Branchinecta at Leadville, Colorado."

WILLIAM D. WALTMAN, representing the Franco Wyoming Oil Company, Franco Western Oil Company, McElroy Ranch Company and Isolantite, Inc., transferred his general offices from New York City to Suite 601, Edison Building, Fifth at Grand, Los Angeles, California, on May 1. Mr. Waltman will still retain his offices at 9 Boulevard de la Madeleine, Paris, and at 422 First National Bank Building, Denver, Colorado; his residence address is Box 37, La Mesa, California.

The San Antonio Section of The American Association of Petroleum Geologists elected the following officers, on March 2, for the ensuing year: president, HERSCHEL H. COOPER, 1442 Milam Building, San Antonio; vice-president, L. W. MACNAUGHTON, 1718 Milam Building; secretary-treasurer, J. D. HEDLEY, 1014 Milam Building. D. R. SEMMES, 1601 Milam Building, retiring president, and ED. W. OWEN, 1015 Milam Building, retiring secretary-treasurer, are members of the executive committee of the section.

FRANK C. GREENE, 1434 South Cincinnati Avenue, Tulsa, Oklahoma, has resumed his practice as consulting geologist.

JON A. UDDEN died on March 15, 1931, at Bentonville, Arkansas.

HARRY F. WRIGHT, consulting geologist and petroleum engineer, Tulsa, was elected chairman for the coming year of the Mid-Continent section of the American Institute of Mining and Metallurgical Engineers. The other officers elected at the meeting of March 9, 1931, are: first vice-chairman, D. L. TRAX, of the Gypsy Oil Company, Tulsa; second vice-chairman, CLAREL B. MAPES, of the Mid-Continent Oil and Gas Association, Tulsa; and secretary-treasurer, WALLACE H. COLLINS, Shell Petroleum Corporation, Tulsa. H. H. POWER, of the Gypsy Oil Company, Tulsa, C. C. RAE, of the Skelly Oil Company, Tulsa, H. B. GOODRICH, consulting geologist, 1628 South Cincinnati, Tulsa, and C. V. SIDWELL, Box 547, Seminole, Oklahoma, are members of the executive committee of the section.

WILLIAM F. LOWE, 1607 East Twelfth Street, Apartment 203, Tulsa, Oklahoma, is a member of the editorial staff of *International Petroleum Technology* (successor to *Oil Field Engineering*), which is published by the National Petroleum Publishing Company of Cleveland, Ohio, with branch offices at Tulsa, New York, Houston, Chicago, and Los Angeles.

B. W. GILLESPIE was recently appointed manager of the export department of the Elliott Core Drilling Company, Los Angeles, California. He succeeds H. A. KASSABAUM, who has resigned.

STANLEY C. HEROLD, consulting geologist and engineer, Los Angeles, California, has an article in the March 12 issue of *The Oil and Gas Journal*, entitled "One Kettleman Guess Good As Another," in regard to estimates of probable recovery from this field. Mr. Herold also has a paper, "On and Off the Dome at Kettleman Hills," in the March issue of the *Oil Bulletin*.

ERNEST R. LILLEY, professor of economic geology, New York University, New York City, has a paper entitled "Petroleum Education and Research Facilities in Great Britain" in the April, 1931, issue of *Mining and Metallurgy*. This paper was presented before the annual meeting of the American Institute of Mining and Metallurgical Engineers, February, 1931.

W. B. HEROY, of the Sinclair Exploration Company, New York City, presented a paper on "Petroleum Development in Africa" before the annual meeting of the petroleum division of the American Institute of Mining and Metallurgical Engineers, in New York City, February, 1931. The paper is published in the March 21 issue of *The Petroleum Times* (London).

The School of Petroleum Engineering of the University of Oklahoma, Norman, is offering an eight-week field course in the petroleum industry, from June 11 to August 7, 1931. Information relative to the course may be obtained from H. C. GEORGE, director of the school of petroleum engineering.

ELIOT BLACKWELDER, of Stanford University, California, has an article on "Desert Plains" in the February-March, 1931, issue of *The Journal of Geology*.

K. A. SIMMONS, formerly of the Shell Petroleum Corporation, is now in the employ of W. C. McBride, Inc., 704 Shell Building, St. Louis, Missouri. Mr. Simmons' present address is Box 697, Tyler, Texas.

JOHN B. REESIDE, JR., of the United States Geological Survey, Washington, D. C., and A. ALLEN WEYMOUTH, of the California Company, Denver, Colorado, are co-authors of "Mollusks from the Aspen Shale (Cretaceous) of Southwestern Wyoming," published in 1931 as *Proceedings of the United States National Museum No. 2860*.

MARTIN VAN COUVERING, consulting petroleum engineer of Los Angeles, California, has been appointed a member of the Committee on Petroleum Economics, which is sponsored by the Federal Oil Board.

C. P. DUNBAR, formerly with the United States government in Haiti in soil survey and paleontological work, has been named paleontologist for the minerals division of the Louisiana Conservation Commission, with headquarters in Shreveport.

The Society of Petroleum Geophysicists, Houston, Texas, has elected the following officers for the coming year: president, DONALD C. BARTON, consulting geologist and geophysicist, Houston; vice-president, G. H. WESTBY, Empire Oil and Refining Company, Bartlesville, Oklahoma; secretary-treasurer, JOHN F. WEINZIERL, consulting geologist and geophysicist, Houston; and editor, PAUL WEAVER, of the Gulf Production Company, Houston.

DAVID WHITE, senior geologist of the U. S. Geological Survey, Washington, D. C., is recovering from a serious illness.

HEDWIG T. KNIKER has opened a paleontological laboratory in the Alamo National Building, San Antonio, Texas. This notice is a correction of the item which appeared in this department in the March *Bulletin*.

CHARLES A. STEWART is district geologist for the United Gas Corporation at San Antonio, Texas, with offices in the Smith-Young Tower.

B. RIXLEBEN, formerly with the Minnehoma Oil and Gas Company, has established the Map-It-Right Geological Service at Tulsa, Oklahoma, and will specialize in surface interpretation.

N. J. M. TAVERNE, of the Shell Petroleum Corporation, The Hague, Holland, formerly vulcanologist for the Dutch government, addressed the Tulsa Geological Society, April 6, 1931, on a "Survey of Vulcanism in the Dutch East Indies."

One of our members has suggested that members who have back numbers of the paper-covered *Bulletin* which they are replacing with cloth-bound volumes, might give the paper numbers to local libraries or educational institutions. The Association desires to purchase Volume I complete, and copies of *Geology of Salt Dome Oil Fields*. Address Association headquarters, Box 1852, Tulsa, Oklahoma.

WILL F. EARL, recently with the Mid-Kansas Oil and Gas Company at Tulsa, Oklahoma, is now located at 822 Coolidge Avenue, Wichita, Kansas.

Helen Hughes, daughter of Mr. and Mrs. C. DON HUGHES, was born, March 24, 1931, at Amarillo, Texas.

FRED A. DAVIES is assistant general manager of The California Company, at Dallas, Texas.

CORBIN D. FLETCHER, of Jackson, Mississippi, died April 5 at Meridian, Mississippi, as the result of an injury received from the collapse of a roof at an abandoned house at Riderwood, Alabama, where Mr. Fletcher and his partner, H. N. TOLER, were eating lunch. Mr. Fletcher was recently geologist and micropaleontologist for the Gulf Refining Company, Shreveport, Louisiana.

JOSEPH H. TURNER, formerly of 406 Milam Building, San Antonio, Texas, is now associated with GILBERT WOOD, Box 236, Wellsboro, Pennsylvania.

CHARLES SCHUCHERT, of Yale University, has rewritten his *Outlines of Historical Geology*, and the second edition has been published by John Wiley and Sons ($3.00).

WITHERS CLAY plans to spend the summer with his family, in the lake region of northern Minnesota. His mailing address is in care of O. M. Oulman, 3109 Holmes Avenue, South, Minneapolis, Minnesota.

JOHN T. LONSDALE, of the geological department of Texas A. and M. College, addressed the San Antonio Geological Society, March 6, 1931, on the problems of underground water supply in southwest Texas and the chemical characteristics of that water.

I. P. TOLMACHOFF, Carnegie Museum, Pittsburgh, Pennsylvania, has a brief article in the April 3 issue of *Science*, entitled "The Use of the Divining Rod in Gold Prospecting in Alaska."

T. WAYLAND VAUGHAN, director of the Scripps Institution of Oceanography, at La Jolla, California, has been elected a member of an advisory committee on the "General Bathymetric Chart of the Oceans" of the International Hydrographical Bureau of Monaco.

J. E. EATON, consulting geologist, Los Angeles, California, has a brief article in the April issue of *Petroleum World*, entitled "Basic Requirements for Improvement."

H. E. CRUM, formerly of the Skelly Oil Company at Amarillo, Texas, is now with the Columbian Carbon Company, Charleston, West Virginia.

LOUIS CHAPPUIS, 2031 East Hope Street, Huntington Park, California, has an article entitled "Peru's Place in the Petroleum Panorama" in the April issue of *Petroleum World*.

HUGO R. KAMB, of the Louisiana Oil Refining Company, at Shreveport, addressed the Shreveport Geological Society at its April meeting, on the subject of "Limestone Reservoirs."

H. RIES, of the department of geology, Cornell University, is the author of *Elementary Economic Geology*, published by Wiley and Sons.

ALFRED GRAY, of the Atlantic Oil Producing Company, has been transferred from Carlsbad, New Mexico, to Dallas, and EDGAR KRAUS has been transferred from San Angelo, Texas, to Carlsbad.

SAM M. ARONSON, of the Atlantic Oil Producing Company, has been transferred from Dallas to take charge of subsurface work at San Angelo, Texas.

J. MARVIN WELLER, of the Illinois State Geological Survey, Urbana, Illinois, has a paper in the April, 1931, issue of the *American Journal of Science*, entitled "Sedimentary Cycles in the Pennsylvanian Strata: A Reply." This is a reply to T. E. Savage's paper, "Sedimentary Cycles in the Pennsylvanian Strata," which was published in the August, 1930, number of the *Journal*.

Laymen's interest in geology has reached a new high point at Tulsa, as evidenced by the recent action of the Board of Park Commissioners of the City of Tulsa, in establishing a division of geology and laying plans for a geological museum at Mohawk Park. A tract of ground approximately 800 × 200 feet in dimensions has been set aside for the purpose of installing buildings for fossils, maps and minerals, as well as an extensive outdoor display of rocks. FOREST REES, Tulsa oil geologist, has been chosen as curator of geology as the result of acceptance of his plans for the enterprise and he has already begun assembling material for the installation.

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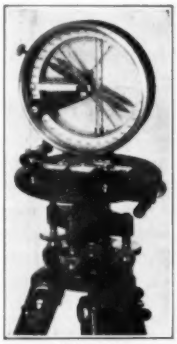

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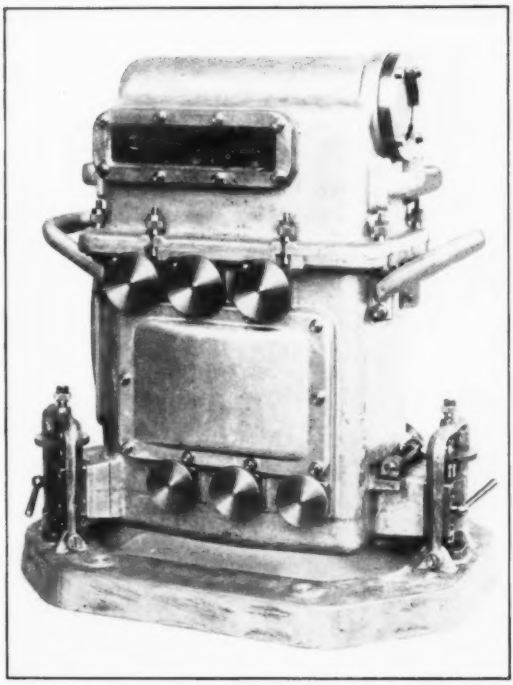

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